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Testing of Indoor Radon Reduction Techniques in 19 Maryland Houses

CDM Federal Programs Corp., Fairfax, VA

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16. ABSTRACT

The report gives results of testing of indoor radon reduction techniques in 19 existing houses in Maryland. The focus was on passive measures: various passive soil depressurization methods, where natural wind and temperature effects are utilized to develop suction in the system; and sealing of radon entry routes into the house. Active (fan-assisted) soil depressurization techniques were also tested. Passive soil depressurization systems typically gave moderate radon reductions (30-70%), although the reductions ranged from zero to 90%. Only two houses were reduced < 4 pCi/L with the passive systems. A passive system is most likely to be successful when sub-slab communication is very good, when the house has a basement with no adjoining slab-on-grade or crawl-space wings, and when the foundation walls are poured concrete instead of hollow block. Entry route sealing as a stand-alone radon mitigation measure gave zero-50% reduction in the only house where it was tested. Active soil depressurization, tested in 18 houses, reduced 16 of them < 4 pCi/L, and 12 of them < 2 pCi/L; reductions were often > 90%. Poor sub-slab communication prevented this approach from being fully successful in the other two houses; later modifications to these two systems reduced these houses < 4 pCi/L also.

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ABSTRACT

Indoor radon reduction techniques were tested in 19 existing houses in Maryland. The primary objective was to assess the effectiveness of passive mitigation measures, including passive soil depressurization and entry route sealing. Passive soil depressurization techniques tested included sub-slab depressurization (SSD), drain tile depressurization (DTD), sub-liner depressurization (SLD) in crawl spaces, and block wall depressurization (BWD). Active (fan-assisted) depressurization was also tested. All but one of the houses had basements, sometimes with an adjoining slab-on-grade or crawl-space wing; one house was a slab on grade.

The passive soil depressurization systems (in 12 of the houses) typically gave moderate radon reductions (30 to 70%), although the reductions ranged from zero to 90%. Only two of the houses were reduced below 4 pCi/L with the passive systems. A passive system is most likely to be successful when: a) the sub-slab communication is very good; b) the basement has no adjoining wing; and c) the foundation walls are poured concrete instead of hollow block. Performance of these systems vary with wind and temperature. Only one or two passive suction pipes were used in these installations; better performance might have been achieved with more pipes.

Entry route sealing as a stand-alone mitigation measure was tested in one house where all apparent entry routes were accessible. Limited, if any, radon reductions were achieved (0 to 50%), perhaps in part because the waterproofing paint applied to the capped block foundation walls apparently did not seal all of the block pores.

Active soil depressurization was the final approach tested in 18 of the 19 houses. In 16 of these houses, radon levels were reduced below 4 pCi/L (and, in 12 of the houses, below 2 pCi/L). In the other two houses, poor and uneven sub-slab communication prevented the one-pipe SSD systems from being fully successful. (Subsequent modification of these two systems to include one or two additional suction pipes, following completion of this project, resulted in levels below 4 pCi/L.) Where communication is good, active SSD or DTD systems appear capable of treating entry routes associated with block foundation walls. Also, where communication is good and where the adjoining wing is not a major source, systems treating only the basement in basement-plus-adjoining-wing houses appear able to adequately reduce radon in the entire house, without a component of the system specifically treating the adjoining slab on grade or crawl space.

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METRIC CONVERSION FACTORS

Although it is EPA's policy to use metric units in its documents, non-metric units have been used in this report consistent with common practice in the radon mitigation field. Readers more accustomed to the metric system may use the following factors to convert to that system.

Non-Metric	Times	Yields metric
picoCurie per liter (pCi/L)	37	Becquerel per cubic meter (Bq/m^3)
inches of water gauge (in. WG)	248	Pascals (Pa)
mil (0.001 inch)	0.0254	millimeter (mm)
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.305	meter (m)
mile (mi.)	1.61	kilometer (km)
square foot (ft^2)	0.0929	square meter (m^2)
cubic foot (ft^3)	28.3	liter (L)
cubic foot per minute (cfm)	0.47	liter per second (L/s)
gallon (gal)	3.79	liter (L)
microRoentgen (μR)	2.58×10^{-10}	coulomb per kilogram of air (C/kg)
degrees Fahrenheit (°F)	5/9 (°F - 32)	degrees Centigrade (°C)

CHAPTER 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is conducting a radon mitigation R,D&D program to identify and evaluate cost-effective techniques for reducing elevated radon levels in houses. The total EPA program will evaluate the full range of radon reduction methods (i.e., house ventilation, sealing of entry routes, soil ventilation, house pressure adjustment, radon removal from well water, and air cleaning), in the full range of housing substructure types, construction methods, and geological conditions representative of the U. S. housing stock. The program described in this report was to demonstrate selected radon reduction methods in housing and geology typical of Maryland.

This project involved testing of radon mitigation systems in 19 existing Maryland houses. These houses have structures that are representative of this region: 18 have basements with concrete slabs (sometimes with an adjoining slab-on-grade or crawl-space wing), while the remaining house is of slab-on-grade construction. The foundation walls are hollow block in 13 of the houses, and poured concrete in the 6 others. Pre-mitigation radon levels ranged from 7 to 298 pCi/L[1], with most houses having radon levels greater than 10 pCi/L.

The major objective of this project was to evaluate passive systems (that is, systems not requiring the operation of a fan). Such systems have not been widely tested in other projects. Passive systems include: passive soil depressurization, i.e., soil depressurization not involving the use of a fan; sealing of soil gas entry routes; and natural ventilation of the house or crawl space. A key potential advantage of passive systems is that they do not require homeowner maintenance of a fan, and avoid the cost and any noise associated with fan operation. Disadvantages include potentially limited and variable radon reduction performances due to, e.g., the limited nature of the natural suction that is developed in passive soil depressurization stacks by thermal and wind effects, and the difficulty in effectively accessing and addressing essentially all soil gas entry routes when attempting sealing as the sole mitigation measure. In this project, the intent was to determine the degrees of radon reduction that could be achieved with a reasonable best effort to retrofit passive systems into typical existing houses.

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[1] Conversion factors to metric units are given on page ix.

In view of this objective, passive systems were initially installed in 13 of the houses where structural features appeared reasonably conducive to this approach. Twelve of these were passive soil depressurization systems (often in conjunction with sealing or natural crawl-space ventilation), and one involved purely sealing. (In all cases, active, or fan-assisted, soil depressurization was considered a back-up approach to be installed in the event that the initial passive systems did not achieve sufficient reductions.) In the remaining 6 houses, where conditions appeared less favorable for passive measures, active soil depressurization systems were the initial approach of choice.

This project was completed by CDM Federal Programs Corporation, with the assistance of its parent firm, Camp Dresser & McKee, Inc. ARIX Corporation had primary responsibility for direct design and installation of all of the mitigation systems. G.M.D. Construction, Inc., and J. C. Armstead Corporation -- representing mitigation firms serving the Maryland area -- each installed four of the systems under CDM and ARIX supervision.

This project was sponsored by EPA under Contract No. 68-02-4268, and was carried out in cooperation with the Maryland Department of the Environment.

CHAPTER 2

SUMMARY AND CONCLUSIONS

1. Passive soil depressurization techniques, relying upon temperature and wind effects to create natural suction in the system, were tested with a total of 14 mitigation installations in 12 houses. The passive techniques tested included sub-slab depressurization (SSD), drain tile (sump) depressurization (DTD), and sub-liner depressurization (SLD) in crawl spaces; these techniques were tested both by themselves, and in certain combinations with each other and with block wall depressurization (BWD). Commonly, some degree of entry route sealing and/or crawl space isolation/natural ventilation was conducted in conjunction with the passive soil depressurization. House substructure types tested included basement houses, and basement houses having adjoining slab-on-grade or crawl-space wings.

2. The passive soil depressurization systems typically provided moderate radon reductions (30 to 70%), although the reductions ranged from as low as zero to as high as 90%. In only two of the houses (Houses 047 and 079) was the passive system sufficient to consistently reduce radon below 4 pCi/L both in the basement and in the living area.

3. The house which gave the best reductions consistently (House 079, which achieved 70 to 90% reduction with each measurement as the result of a one-pipe passive SSD system) was a textbook-case house for a passive system: a) it was a "pure" basement, without an adjoining wing; b) it had very good sub-slab communication; and c) it had poured concrete foundation

walls, thus minimizing wall-related entry routes. The one other house which also met all three of these criteria (House 004) also achieved good reductions, 60 to 80% in the basement.

4. The other house which achieved radon concentrations below 4 pCi/L was House 047, a basement-plus-crawl-space house which achieved 20 to 70% reduction in the basement (and 90 to 96% in the crawl space) using a passive SLD system combined with basement sealing. This house, too, apparently provided a textbook case: a) the exposed crawl-space soil was the primary radon source; b) the crawl space was unobstructed, small, and had reasonable head room; c) the furnace flue was used as the passive stack, enhancing the natural suction developed on the SLD system; and d) the foundation walls were poured concrete, again minimizing wall-related entry.

5. One of the most important single variables influencing the performance of passive soil depressurization systems is the communication beneath the slab. All houses which had poor performance from the passive system (Houses 054 and 074) had poor/uneven sub-slab communication (and block foundations). However, the existence of good communication was not sufficient, by itself, to ensure high radon reductions from the passive system.

6. The performance of passive depressurization systems appeared to be somewhat better in houses having poured concrete foundation walls. In all of the houses having poured walls, the upper end of the performance range with a passive system was above 70% reduction. By comparison, of the 7 block-foundation houses to receive passive systems, only 3 achieved upper-end reductions greater than 50%. This could be due in part to difficulty by the low-suction passive systems in treating the wall-related entry routes. In House 106, a

basement-plus-slab-on-grade house with a block foundation, performance improved perceptibly (from 0 - 50%, to 30 - 85%) when the original passive SSD system was expanded to include a BWD component, confirming the failure of the original SSD system to adequately treat the wall in this case.

7. For a given degree of sub-slab communication, and for a given material of construction for the foundation wall, it is not possible from these data to determine a significant effect of the substructure type on the performance of the passive systems. Except perhaps for textbook-case Houses 004 and 079 (which were pure basements), it is not possible, within the error bar of these results, to identify whether the passive systems give better performance in pure basement houses than they do in basements with adjoining wings.

8. In the passive SSD installations, a limited number of suction points were installed to minimize installation costs. The installation of additional sub-slab suction holes, or of a passive BWD component when block foundation walls were present, might have improved the performance of the passive systems.

9. The performance of a given passive system is presented as a range in this report because: a) the pre- and post-mitigation measurements are separated in time in many cases, and the radon source term might have changed between measurements; and b) the performance of the passive systems would appear to be varying over time, depending upon wind conditions and temperature.

10. The suctions developed in the piping of these passive systems were typically in the range of 0.0 to 0.10 in. WG. If sub-slab communication was very good, the resulting depressuriza-

tion underneath the slab was observed to extend as far as 40 ft from the suction pipe in one house, although the magnitude of this depressurization fluctuated, presumably due to varying winds.

11. Entry route sealing, as a passive mitigation measure by itself, was tested in one house which appeared amenable to this approach. The house was a pure basement house; the basement was unfinished, with all apparent entry routes accessible; and radon levels were only slightly elevated, so that high radon reductions were not necessary. The house had block foundation walls, capped with solid blocks. After sealing all apparent entry routes -- including painting the block walls with a waterproofing paint -- the radon reduction, if any, was limited (0 to 50%). This limited performance may be due in part to the fact that the paint did not appear to fully seal the block pores.

12. Active soil depressurization was tested in 18 of the 19 houses. All but one of the 13 houses with passive systems, discussed above, were converted to active systems by the end of the project. In addition, 6 houses received active systems immediately, because they did not appear to be amenable to passive testing (due to highly-elevated pre-mitigation radon levels or to poor communication). The types of active techniques tested covered the range indicated for the passive systems in 1 above. The house substructure types included basement and basement-plus-adjoining-wing houses, and one slab-on-grade house.

13. Radon levels were reduced to below 4 pCi/L, in both the basement and the living area, in 16 of the 18 houses where active depressurization systems were installed. Levels were reduced below 2 pCi/L on both stories in 12 of these houses.

The radon reductions typically were above 90% in the 16 houses, and often ranged as high as 97 to 99+%, although the percentage reduction sometimes ranged as low as 50 to 80% in cases where the pre-mitigation concentrations were only slightly elevated.

14. In the two houses which were not reduced below 4 pCi/L with the active systems (Houses 054 and 074), the reason was poor and uneven communication underneath the basement slab. (These two houses were subsequently reduced below 4 pCi/L by adding additional suction pipes in regions of the slabs where the suction field had not been extending with the initial single pipe.)

15. It is not apparent from these data that active systems performed any better in houses with block foundations than they did in houses with poured foundations. Thus, within the sensitivity of these data, it would appear that these active systems were adequately treating any block-wall-related entry routes, even though only two of the systems included specific BWD components. (However, both of the houses which failed to be reduced below 4 pCi/L did have block walls; block walls may be significant when sub-slab communication is poor.)

16. In four of the houses which were basements with adjoining slab-on-grade or crawl-space wings (Houses 008, 069, 076, and 106), radon levels on both stories were reduced below 4 pCi/L with active soil depressurization treating the basement only. Three of these houses were reduced below 2 pCi/L. All four of these houses were observed to have good aggregate under the basement slab, and/or suction field extension measurements showed good communication. Thus, it appears that -- with these combined-substructure houses -- it is possible to reduce radon in the entire house by treating the basement only,

without specifically treating the adjoining wing, if the basement sub-slab communication is good (and, presumably, if the adjoining wing is not the primary radon source).

17. In general, the active systems achieved high suctions in the system piping (usually 0.4 to 1.6 in. WG, except in cases where suctions were reduced by high flows from BWD legs or some other source). Suctions developed under the slabs at points remote from the suction pipes (20 to 40 ft away) ranged from zero to 0.9 in. WG from house to house, depending upon communication. In a few cases (Houses 096, 126, 143, and 163), good radon reductions were achieved despite the fact that no sub-slab depressurization could be measured at some test holes.

CHAPTER 3

HOUSE SELECTION PROCESS

3.1 INTRODUCTION

The first step of this field project was to select between 15 and 20 existing houses to serve as study houses for the project. A two-step house selection process was utilized. As described below, the selection steps included: 1) a paper screening of a data base developed by the Maryland Department of the Environment (DOE), containing radon measurements and house profile information on 165 houses; and 2) visitations to 56 houses selected from this data base, to obtain information which would permit final selection of the study houses.

3.2 SELECTION CRITERIA

A number of house selection criteria were identified to aid in the selection process.

1. The house must be reasonably representative of Maryland houses, and of other houses of its substructure; it should be of a typical size (1,200 - 2,500 ft^2).

2. The house must be a detached, single-family, owner-occupied house.

3. A range of typical substructures should be addressed (basement, basement with adjoining slab-on-grade or crawl-space wings, slab on grade); and, both poured concrete and hollow-block foundation wall should be addressed.

4. The pre-mitigation radon concentration should be at least 10 pCi/L, to permit reliable measurement of the effects of the mitigation system to be installed.

5. All houses should be located within a 25-mile radius, for reasonably convenient access.

6. The house should be no more than 40 years old.

3.3 SELECTION PROCESS

To develop a pool of Maryland homeowners from which to select participants for this project, the Maryland DOE placed an advertisement in several newspapers explaining the project and providing an application form. To be eligible, the homeowners were required to live within a 25 mile radius of a location approximately 5 miles east of Mt. Airy, Maryland (an area including portions of Frederick, Carroll, Baltimore, Montgomery, and Howard Counties). Also, they were required to live in a detached, single family, owner-occupied house that was less than 40 years old and with 1,200 to 2,500 square feet of living space. It was also necessary for the homeowners to have previously measured the radon concentrations in their homes using a laboratory participating in EPA's Radon Measurement Proficiency Program, and to have found a level of 10 pCi/L or greater.

A total of 180 homeowners satisfying these initial screening requirements responded to the advertisement. DOE then sent a one-page house profile questionnaire to these homeowners, requesting various information on house characteristics. The form requested information on, e.g., substructure type, foundation wall material, house size and age, heating system, presence of certain key radon entry routes, etc. House profile questionnaires were returned by 165 homeowners before the May 1987 deadline. EPA then used this data base to identify 56 candidates for on-site house evaluations.

During a 5-day period in June 1987, the 56 houses were visited by one of two teams composed of personnel from EPA, the State of Maryland, CDM Federal Programs Corporation, and ARIX. Each house received a one hour walk-through, during which a house summary questionnaire was completed documenting various house characteristics. Grab samples of indoor air, or of air from potential entry routes, were also collected to estimate radon and radon progeny concentrations.

3.4 SELECTION OF STUDY HOUSES

From the group of 56 houses that were visited, 19 houses were selected for inclusion in this project, based upon the selection criteria. A list of some of the key features of these 19 houses is presented in Table 1. The radon concentrations shown in the table are short-term, charcoal-detector measurements which had been obtained by the homeowners prior to this project (probably during the winter of 1986-87).

Following selection of the houses, during August 1987, an additional pre-mitigation charcoal detector measurement was made in each house as part of this project. In addition, a 48-hour pre-mitigation continuous radon measurement was made using a Pylon instrument, at some point during the period October 1987 through February 1988. These short-term pre-mitigation measurements are summarized in Table 2, along with the previous charcoal measurements that had been made by the homeowners. The charcoal measurement made under this project was commonly lower than the other pre-mitigation measurements, probably because that measurement was made during the mildest weather of the three measurements.

TABLE 1. FEATURES OF THE 19 HOUSES SELECTED

House	Pre-Mitigation Radon (pCi/L)[1]	Foundation	Substructure
004	64.3 (bsmt) 37.5 (LA)	Poured	Basement
008	64.9	Poured	Basement + slab-on-grade
010	17.6 (bsmt) 11.8 (LA)	Block	Basement
011	135-178	Block	Basement + slab-on-grade
032	11.5 (bsmt) 6.4 (LA)	Block	Basement
041	265.2 (bsmt) 231.6 (LA)	Poured	Basement + slab-on-grade
047	11.1	Poured	Basement + crawl space
054	23.2	Block	Basement + crawl space
061	12.0	Block	Basement
069	20.0 (bsmt) 13.2 (LA)	Block	Basement + crawl space
074	27.8 (bsmt) 13.0 (LA)	Block	Basement + crawl space
076	16.8	Poured	Basement + crawl space
079	20.2 (bsmt) 10.6 (LA)	Poured	Basement
096	15.7 (LA)	Block	Basement + slab-on-grade
106	19.2 (bsmt) 7.1 (LA)	Block	Basement + slab-on-grade
110	31 (LA)	Block	Slab-on-grade
126	44.7	Block	Basement + crawl space
143	46.8-57.2 (LA)	Block	Basement
163	19.1 (bsmt) 13.1 (LA)	Block	Basement + crawl space

[1] Short-term radon concentrations measured by homeowners prior to project, using charcoal detectors. Radon levels are measured in basement (bsmt), unless indicated as having been measured in living area (LA); living area can be area above basement, or area on adjoining slab-on-grade, or area above adjoining crawl space.

TABLE 2. SUMMARY OF VARIOUS PRE-MITIGATION RADON MEASUREMENTS IN THE 19 SELECTED HOUSES

House	Story	Pre-Mitigation Concentrations (pCi/L) Charcoal Measurement by Owner[1]	Charcoal Measurement (This Project)[2]	Average Pylon Measmt.[3]
004	Bsmt	64.3	24.1-24.5	39
	LA	37.5	--	25
008	Bsmt	64.9	11.9-12.5	8.3
	LA	--	--	5.3
010	Bsmt	17.6	11.3-13.6	6.8
	LA	11.8	--	2.3
011	Bsmt	135-178	5.7- 7.2[4]	88.3
	LA	--	--	43.1
032	Bsmt	11.5	7.8- 7.9	11.9
	LA	6.4	--	10.0
041	Bsmt	265.2	15.0-15.3[4]	298
	LA	231.6	--	222
047	Bsmt	11.1	3.2-14.3	6.5
	LA	--	--	--
	Crawl	--	--	28.5
054	Bsmt	23.2	10.2-12.2	12.4
	LA	--	--	--
	Crawl	--	--	8.7
061	Bsmt	12.0	11.4-14.5	9.1-12.3
	LA	--	--	--
069	Bsmt	20.0	9.4- 9.8	13.2
	LA	13.2	--	8.5
074	Bsmt/Crawl	27.8	7.6	16.2
	LA	13.0	--	--
076	Bsmt	16.8	4.3- 7.9	9.5
	LA	--	--	4.3
079	Bsmt	20.2	12.4-12.5	17.3-24.0
	LA	10.6	--	--

(continued)

TABLE 2 (continued)

House	Story	Pre-Mitigation Concentrations (pCi/L) Charcoal Measurement by Owner[1]	Charcoal Measurement (This Project)[2]	Average Pylon Measmt.[3]
096	Bsmt	--	16.2-17.0	23.0
	LA	15.7	--	4.3
106	Bsmt	19.2	14.1-14.4	58
	LA	7.1	--	18
110	Bsmt	N/A	N/A	N/A
	LA	31	11.4-12.7	23.8-26.2
126	Bsmt	44.7	44.9-46.2	--[5]
	LA	--	--	3
143	Bsmt	--	41.3-45.4	71[4]
	LA	46.8-57.2	--	36.8
163	Bsmt	19.1	4.3- 4.8	31.0
	LA	13.1	--	18.5

[1] Charcoal detectors deployed by homeowner prior to project, probably during the winter 1986-87.

[2] Charcoal detectors, generally deployed in duplicate in the basement, during August 1987 (mild weather). The range of radon levels shown reflects the results from both detectors.

[3] The average of about 48 hours of hourly Pylon measurements conducted prior to any mitigation, at some point during the period October 1987-February 1988. Where a range is shown, two Pylons were placed on the indicated story.

[4] The basement was being ventilated during this measurement.

[5] Basement in House 126 was open to the outdoors during Pylon measurement period (crawl space being converted to basement).

Bsmt = basement; LA = living area; Crawl = crawl space.

CHAPTER 4

PROJECT APPROACH

In accordance with project objectives, the initial mitigation system installed in each house was a passive system wherever practical. These initial ("Stage 1") systems involved passive installations in 13 of the houses; 12 of these houses received passive soil depressurization (usually in conjunction with sealing or natural crawl-space ventilation steps), and 1 house was treated by sealing alone. The passive soil depressurization systems involved connecting a passive stack to: one or more pipes penetrating the basement slab (passive sub-slab suction); or an existing sump (passive interior drain tile suction); or perforated piping underneath a plastic liner over exposed soil in a crawl space (passive sub-liner suction). The passive stack was generally a PVC pipe which went up through the interior of the house and terminated on the roof with a wind turbine; in three cases, the mitigation piping was connected to an existing central furnace flue duct, utilizing the flue as the passive stack.

The remaining 6 houses received active soil depressurization systems in Stage 1. There were two primary reasons for proceeding immediately with active systems in these 6 houses: 1) pre-mitigation radon concentrations were so highly elevated that it was doubtful that passive systems could provide sufficient reductions; and/or 2) the house provided complications which suggested that passive systems would be insufficient or impractical, e.g., poor or uneven sub-slab communication, or the absence of a route for a passive stack up through the house.

Short-term pre- and post-mitigation radon measurements (2- to 4-

day measurements with a continuous monitor) were made to assess the performance of the Stage 1 systems. In some cases, sufficient time was available to complete post-mitigation 3-month alpha-track detector measurements between Stage 1 and the successive steps. Various diagnostic measurements were also made on the Stage 1 systems.

Based upon the evaluation of the Stage 1 installations, it was apparent that modifications were necessary to improve the performance of all but one of the passive systems, due to elevated residual radon levels. (All 6 of the active Stage 1 systems performed well, and did not require any further modifications.) This first series of modifications to the initial systems is referred to as "Stage 2". In 9 of the 12 houses requiring Stage 2 modifications, the passive system was converted to an active system, generally by adding a fan to the previous piping. In the other 3 Stage 2 houses, an attempt was made to bolster the initial Stage 1 passive system with additional passive steps: additional passive sub-slab or block-wall suction pipes, and/or additional sealing. Radon measurements and diagnostic testing were carried out on the Stage 2 systems.

Based upon the Stage 2 measurements, the 3 passive systems which had been upgraded in Stage 2 were further modified in "Stage 3". In all 3 cases, the passive systems were converted to active systems. Thus, at the end of the project, only one of the 19 houses (House 047) retained a passive mitigation system.

A list of the installation dates for each test stage in each house is presented in Table 3. The mitigation systems installed in each house during Stages 1, 2 and 3 are summarized in Tables 4, 5, and 6, respectively. As apparent from Table 3 -- considering the Stage 2 and Stage 3 modifications made in the various houses -- a total of 34 installations were made in the 19 houses.

The mitigation systems are further described in the discussion of results in Sections 6 through 11. Detailed descriptions of the work done during each stage in each house are presented in Appendix C.

TABLE 3. INSTALLATION SCHEDULE

House	Stage 1	Stage 2	Stage 3
004	11/87	7/88	-
008	3/88	12/88	-
010	1/88	7/88	12/88
011	11/87	-	-
032	3/88	12/88	-
041	1/88	-	-
047	11/87	-	-
054	3/88	7/88	-
061	3/88	12/88	-
069	1/88	7/88	12/88
074	3/88	7/88	-
076	3/88	12/88	-
079	3/88	12/88	-
096	11/87	12/88	-
106	3/88	7/88	12/88
110	3/88	-	-
126	4/88	-	-
143	1/88	-	-
163	3/88	-	-

TABLE 4. STAGE 1 MITIGATION SYSTEMS

House	Installation Date	Mitigation System
004	11/87	Passive sub-slab suction (two pipes in basement) + w/f sealing[1]
008	3/88	Passive sub-slab suction (one pipe, bsmt)
010	1/88	Entry route sealing in basement
011	11/87	Active sub-slab suction (two pipes under slab on grade, two pipes in basement)
032	3/88	Passive sub-slab suction (one pipe, bsmt)
041	1/88	Active sub-slab suction (two pipes under slab on grade, two pipes in basement) + sealing
047	11/87	Passive sub-liner suction (crawl space) + sealing (basement)
054	3/88	Passive sub-slab suction (one pipe, bsmt) + increased natural ventilation (crawl)
061	3/88	Passive sump (drain tile) suction
069	1/88	Passive sub-slab suction (one pipe, bsmt) + w/f sealing (bsmt) + increased natural ventilation (crawl) + isolation of crawl from basement
074	3/88	Passive sub-slab suction (one pipe, bsmt) + w/f sealing (bsmt) + passive sub-liner suction (crawl space)
076	3/88	Passive sub-slab suction (one pipe, bsmt) + isolation of crawl space from basement
079	3/88	Passive sub-slab suction in bsmt (using existing sump crock, no drain tiles) + w/f sealing
096	11/87	Passive sump (drain tile) suction in bsmt + passive sub-slab suction (two pipes) under slab on grade

(continued)

TABLE 4 (continued)

House	Installation Date	Mitigation System
106	3/88	Passive sub-slab suction (one pipe, bsmt) + sealing in basement
110	3/88	Active sub-slab suction under slab on grade (three pipes)
126	4/88	Active sub-slab suction (one pipe in original basement) + active drain tile suction (interior loop under slab of bsmt addition/converted crawl space)
143	1/88	Active sub-slab suction (one pipe, bsmt)
163	3/88	Active sub-slab suction (one pipe in basement) + active sub-liner suction (crawl space)

[1] "W/f sealing" refers specifically to sealing of wall/floor joint using flowable urethane caulk (after routing or removal of existing expansion joint material). Where the term "Sealing" appears without the w/f modifier, sealing steps in addition to sealing of the wall/floor joint were also employed.

TABLE 5. STAGE 2 MITIGATION SYSTEMS

House	Installation Date	Mitigation System
004	7/88	Active sub-slab suction (two pipes, bsmt)
008	12/88	Active sub-slab suction (one pipe) + sump (drain tile) suction in basement
010	7/88	Additional entry route sealing (bsmt)
032	12/88	Active sub-slab suction (one pipe, bsmt)
054	7/88	Active sub-slab suction (one pipe, bsmt) (+ increased vent of crawl, as before)
061	12/88	Active sump (drain tile) suction (bsmt)
069	7/88	Passive sub-slab suction (no. of pipes increased to two) + wall suction (one pipe) in basement (+ increased vent, isolation of crawl, as before)
074	7/88	Active sub-slab suction (one pipe, bsmt) + sub-liner suction (crawl)
076	12/88	Active sub-slab suction (one pipe, bsmt) (+ isolation of crawl, as before)
079	12/88	Active sub-slab suction (one pipe, bsmt)
096	12/88	Active sump (drain tile) suction (bsmt) + active sub-slab suction (two pipes, slab on grade)
106	7/88	Passive sub-slab suction (one pipe, bsmt, as before) + passive block wall suction (two pipes, bsmt)

TABLE 6. STAGE 3 MITIGATION SYSTEMS

House	Installation Date	Mitigation System
010	12/88	Active sump (drain tile) suction (+ sealing, as before)
069	12/88	Active sub-slab suction (two pipes) + active wall suction (one pipe) in bsmt (+ increased vent, isolation of crawl space, as before)
106	12/88	Active sub-slab suction (one pipe) + active block wall suction (two pipes) in basement (+ sealing, as before)

CHAPTER 5

MEASUREMENT TECHNIQUES

5.1 RADON MEASUREMENTS

Pre- and post-mitigation radon levels in the 19 houses were measured using short-term (2- to 4-day) sampling/measurement techniques. Post-mitigation measurements were also made using long-term techniques intended to determine the annual average levels in the house.

5.1.1 Short-Term Radon Measurements

Almost all short-term radon measurements were made with Pylon AB-5 continuous radon monitors. These monitors were equipped with 285 mL Lucas scintillation cells, and were programmed to collect hourly radon samples over a 2- to 4-day period. Each instrument operated by collecting one 10-minute sample each hour, and measuring alpha-decay counts from that sample during six 10-minute intervals (including the 10-minute period while the sample was being drawn). The raw data were stored internally in the instrument; these data were downloaded into a portable computer carried by the field technician, and were converted to radon levels for each hourly 10-minute sample. Only the five 10-minute intervals that followed the 10-minute sampling period were used to determine the average radon level each hour.

Short-term radon measurements were typically made at one location in the basement and at one location on the first floor. Closed-house conditions were established 12 hours prior to sampling and were maintained throughout the testing period. In accordance with current EPA sampling protocols, the instruments were placed at least 2 feet above the floor and away from windows, exterior walls, and HVAC registers.

In each of the 19 houses, the Pylons were used to collect about 2 days of hourly pre-mitigation data, prior to the initiation of the installation activities. These pre-mitigation measurements, made in cool weather during the period October 1987 through February 1988, generally preceded the actual installation of a test system by a month or more, and were intended to help characterize the house.

The Pylons were also used to make 2- to 4-day post-mitigation measurements, to provide a rapid indication of the short-term radon reductions achieved by the mitigation systems and to thus quickly identify whether modifications to the systems were necessary. In many cases -- where the mitigation system could be turned "on" and "off" (by turning the fan on or off, or by capping the passive stack) -- back-to-back Pylon measurements were made with the system on and off (2 days on, 2 days off), to reduce the effects of temporal/seasonal radon variability on apparent system performance. Unfortunately, these back-to-back on/off measurements were not always completed during cold weather, and, in addition, the sealing steps that had been taken could not be "turned off". These factors complicate the interpretation of the results, especially in view of the relatively low pre-mitigation radon levels that existed in some of the houses, and the limited to moderate reductions achieved by many of the passive systems.

Conducting the back-to-back on/off measurements in active mitigation systems was a simple matter, involving turning the power to the fan on or off. Turning the passive depressurization systems on and off was more difficult. With many of the passive systems, the piping leading to the passive stack was severed at one location, and the resulting two sections reconnected using a rubber Fernco coupling. To disable these passive systems for a "system off" measurement, the Fernco coupling was removed, and thick plastic sheeting was placed across both exposed piping ends to seal off the stack. In two houses, the stack configuration prevented this approach. In these cases, large plastic garbage bags were placed over the roof-mounted wind turbines, and sealed with duct tape to prevent the flow of gas up through the depressurization systems for the duration of the "system off" test.

While almost all of the short-term measurements were conducted with the continuous monitors, one pre-mitigation measurement was made in each house during August 1987 using charcoal detectors. Two detectors from EPA's Eastern Environmental Radiation Facility were mailed to each of the 19 homeowners, and deployed by the homeowner (generally in the basement) for an exposure period of about 2 days.

5.1.2 Long-Term Radon Measurements

Alpha-track detectors (ATDs) were employed to measure long-term post-mitigation radon levels, to better determine how the mitigation systems were reducing the homeowners' radon exposures over an extended period of time. The original intent had been to expose ATDs for four successive 3- to 4-month periods over the year after mitigation was complete, with the objective of determining the annual average concentration via four quarterly measurements. Because many of the installations were modified during the course of this year, a full year of ATD data with the final system in place was obtained only for the houses which had been successfully mitigated (by active soil depressurization) in Stage 1. For most of the houses, two or more of the early quarters of ATD measurements were made with one of the intermediate (Stage 1 or 2) systems in place, rather than the final system. However, in all 19 houses, at least one 3- to 4-month ATD measurement was completed after the final system was in place during cold weather, when the challenge to the mitigation system is normally the greatest.

The ATDs were tested in groups of two at most sampling locations, and in groups of three at a few locations, to meet QC objectives. Sampling was normally performed with one location in the basement and one on the first floor. The ATDs were placed in the same rooms where the Pylon monitors had been placed for the short-term pre-mitigation methods, to facilitate comparison. The ATD sampling locations within the rooms were at least 2 feet above the floor, and away from exterior walls, windows, and HVAC registers, in agreement with current EPA protocols.

5.2 PRE-MITIGATION DIAGNOSTIC TESTING

Pre-mitigation diagnostic testing was performed at the 19 houses over the period July through October 1987. Data were collected to facilitate the selection and design of the radon mitigation systems. Information collected included: grab samples for radon gas and radon decay products, in the house air and at suspected entry routes (such as floor/wall joints and sumps); gamma levels; sub-slab communication data and house structural details.

Grab sampling for radon gas was commonly performed using the Pylon AB-5 monitors in a "sniffer" mode, with short elapsed times (about 5 to 10 minutes) between sample collection and counting, and with two 5-minute counting periods. For validation of this sniffer method, some samples were also held for 3 hours before counting, to permit grow-in of the progeny; in all cases, the radon levels determined after 5 minutes compared sufficiently well with the levels determined after 3 hours for diagnostic purposes (always within plus-or-minus 25%, often closer). Grab sampling for radon progeny was accomplished using the Kusnetz procedure, on filter samples obtained using a small pump-driven sampling device.

Indoor gamma measurements were compared to background levels outdoors, to verify that building materials were not a major radon source. In all cases, the indoor readings were in the range of 5 to 12 microRoentgens per hour, lower than the levels measured outdoors, indicating no significant radiation coming from the building materials.

Sub-slab communication tests were conducted using a qualitative procedure involving use of freon gas as a tracer. Freon was typically injected into a hole drilled through the slab. With a high-suction industrial vacuum cleaner, suction was applied to a second sub-slab test hole drilled at a point remote from the first hole (commonly 20 or more feet away). The time required for freon gas to be detected in the other test hole was recorded, and was used as a qualitative indicator of the ease sub-slab communication.

Structural details of the house important to mitigation system design and data interpretation were recorded. This information included type of foundation, construction materials, locations of entry routes, nature of the heating system, etc.

5.3 POST-MITIGATION DIAGNOSTIC TESTING

To evaluate and understand the performance of the mitigation systems, post-mitigation diagnostic tests (in addition to indoor radon measurements) were performed. These tests included measurements of: radon levels, suctions and flow rates in mitigation system piping; the extension of the suction field under the slab; and, sometimes, radon concentrations under the slab, inside block walls, or at potential entry routes, as a means of assessing further mitigation steps. Visual inspections of the mitigation systems were also conducted, to ensure that the mitigation system was properly installed and that entry routes scheduled for sealing had been properly sealed.

Radon concentrations in mitigation system piping, and under slabs and inside block walls, were measured using a Pylon instrument in a grab-sample mode. Flow measurements in system piping were made using an electronic anemometer, sensitive to a velocity of about 10 ft/min. Suction measurements in system piping or underneath the slab were made with a Neotronics electronic micromanometer, sensitive to 0.001 in. WG.

In the three houses where central furnace flues were used as the stack for a passive soil depressurization system, post-mitigation testing included measurements for carbon monoxide. The objective was to ensure that the soil gas flow into the flue was not interfering with the draw of the flue, permitting harmful combustion products to spill or back-draft into the house. A Draeger tube was used to measure CO, sensitive to 3 ppm CO. In all measurements, the CO in the houses was below the detection limit of the method, and was thus well below the OSHA limit of 50 ppm.

CHAPTER 6

SUMMARY OF RADON REDUCTION RESULTS

In Chapters 7 through 11, the results from this testing are discussed on a mitigation technique-by-technique basis. In this chapter, the radon reduction performance data for each of the 34 installations in the 19 houses are presented in some detail. These results will be referred to, usually in a simplified form, in the discussions in the subsequent chapters.

As indicated earlier, indoor radon data were collected using three different measurement methods (2-day charcoal detectors, 2- to 4-day Pylon continuous monitors, and 3- to 4-month alpha-track detectors). In some cases (especially for sealing steps, which cannot be turned "on" and "off"), the pre- and post-mitigation measurements were separated by a month or more, and were sometimes conducted under different climatic conditions. Back-to-back system on/off measurements with soil depressurization systems were often, but not always, made during cold weather, when both the challenge of increased radon entry driving forces, and the natural suction developed in passive stacks, would be expected to be the greatest. Further complicating data interpretation with passive systems is the fact that radon reductions are often limited or moderate, so that it is more difficult to separate out the radon reduction effects of the system from the natural variation of the background radon levels in the house. In view of all these factors, one has to review all of the radon measurements in order to identify the pre- and post-mitigation readings that can most reliably be compared to estimate the actual effect of the mitigation system, particularly with the passive systems. For example, in some cases, the best estimate of system performance can be obtained by comparing short-term pre-mitigation Pylon data obtained one winter against long-term post-mitigation ATD data obtained the following winter, recognizing the uncertainty inherent in this comparison.

The pre- and post-mitigation radon measurements for the entry route sealing systems, the passive depressurization systems, and the active depressurization systems are presented in Tables 7, 8, and 9, respectively. For each installation, results are shown for each measurement method, along with the date of the measurement. All radon measurements made during this project are included in these tables, along with the results from earlier charcoal detector measurements made by the homeowners prior to March 1987. To help illustrate the time differences between the measurements, radon results are listed in order of the date of measurement; pre-mitigation and post-mitigation results are listed on the same line only if they reflect back-to-back system on/off measurements.

A more detailed list of radon measurements for each house is presented in Appendix B.

Estimates of percentage radon removal (usually expressed as ranges) are indicated in Tables 7, 8, and 9, taking into consideration all of the individual measurements that appear reasonably appropriate to compare. The upper bounds of these percentage reduction ranges were calculated by comparing: a) the highest pre- and lowest post-mitigation values indicated in the tables, measured during cold weather; and b) the highest pre- and lowest post-mitigation values obtained during mild weather. The lower bounds were calculated by comparing: a) the lowest pre- and highest post-mitigation values obtained during cold weather; and b) the lowest pre- and highest post-mitigation values obtained during mild weather. In no case were percentage reductions estimated by comparing pre-mitigation data during cold weather with post-mitigation data during mild weather, or vice-versa.

The results in Tables 7, 8, and 9 are summarized in simplified tables in Sections 7 through 11. In those simplified tables, the full range of observed radon concentrations shown in Tables 7 - 9 is presented (including both cold- and mild-weather measurements), as is the range of percentage radon removals. In reviewing the simplified tables, it must be recognized that -- due to the way in which the percentage removal range was calculated, as discussed above -- the percentage reductions cannot be derived simply by comparing the full ranges of pre- and post-mitigation radon values shown in the simplified tables.

Performance of Sealing Alone. As shown in Table 7, efforts to prevent radon entry in House 010 just by sealing accessible potential entry routes did not appear successful. No significant radon reduction was achieved either in the basement or upstairs. For Phase 1 in this house, the sump was capped, the floor/wall joint and interior slab cracks were routed and sealed with flowable urethane caulk, and the joints in the cold-air return ducting to the forced-air heating system in the basement were taped. In Phase 2, the block walls in the basement were painted with waterproofing paint to close the pores (although there is some question whether this paint provided a complete seal). The inability to achieve measurable radon reductions despite this substantial sealing effort is consistent with sealing results reported by others (1).

Performance of Passive Soil Depressurization Systems. A total of 14 passive soil depressurization installations were tested in 12 different houses, as shown in Table 8. In many cases, some sealing effort or crawl-space isolation were also included in the installation. As shown in the table, radon reductions with the passive systems were generally moderate, in the range of 30 to 70% (although there were some reductions both below and above this range). In only two cases (Houses 047 and 079) were basement radon levels reduced unambiguously below 4 pCi/L in both mild and cold weather with passive systems (an apparent reduction of 20-70% in House 047, and 70-90% in House 079). Suctions created in the passive stacks in the 12 houses varied from zero up to 0.1 in. WG, depending upon weather, but were most commonly less than 0.05 in. WG. There is no apparent trend in the data suggesting that the performance of passive systems is being affected by some of the house variables which might have been expected to be important: substructure including a basement only, vs. a basement with an adjoining slab-on-grade or crawl-space wing; basement having sump with drain tiles, vs. no sump; foundation walls built with block vs. poured concrete. The radon reduction results achieved with these systems suggest that passive systems will usually give no better than moderate reductions when retrofit into existing houses, and that reductions can be variable and difficult to predict beforehand.

Performance of Active Soil Depressurization Systems. As shown in Table 9, active soil depressurization systems in 18 of the houses generally reduced radon levels by over 90%, and achieved residual radon concentrations lower than 4 pCi/L, in all but two of the houses (Houses 054 and 074). Ten of the houses were reduced to below 2 pCi/L on both stories during cold-weather measurements (usually with a 3-month, winter-time ATD), and four were reduced below 1 pCi/L on both stories. These active systems primarily involved sub-slab depressurization (SSD) or sump/drain tile depressurization (DTD) systems; where a crawl space was present, sub-liner depressurization (SLD) in the crawl space was sometimes employed, and in Houses 069 and 106, there was a block wall depressurization (BWD) component in addition to SSD. These favorable results are consistent with those achieved by other mitigators in the Washington, D. C., area. In Houses 054 and 074, subsequent sub-slab suction field extension measurements showed that suction was not extending to some portions of the slab.

TABLE 7. RADON REDUCTION PERFORMANCE WITH ENTRY ROUTE SEALING

House No.-Story[1] (Type)[2]	Mit. System	Pre-Mitigation Radon			Post-Mitigation Radon			Estimated % Reduction
		pCi/L	Method[3]	Date	pCi/L	Method	Date	
010 - B	Sealing	17.6	CC	<3/87				0 - 40
(B)	(Stage 1)	11.3-13.6	CC	8/87				
		6.8	Pylon	11/87				
					10.0	Pylon	1/88	
					8.1	Pylon	2/88	
					4.4	Pylon	3/88	
					7.3	ATD	2-5/88	
					9.8	Pylon	5/88	
010 -LA	"	11.8	CC	<3/87				Limited
		2.3	Pylon	11/87				
					4.2	ATD	2-5/8	
010 - B	Improved	17.6	CC	<3/87				0 - 40
(B)	sealing	11.3-13.6	CC	8/87				
	(Stage 2)	6.8	Pylon	11/87				
					9.7-10.4	ATD	8-11/88	
					7.9	Pylon	11/88	
010 -LA	"	11.8	CC	<3/87				0 - 50
		2.3	Pylon	11/87				
					4.7-5.0	ATD	8-11/88	
					4.7	Pylon	11/88	

[1] The story on which the reported measurements were obtained: B = basement; LA = living area.

[2] House types: B = basement; B+SOG = basement with adjoining slab on grade; B+CS = basement with adjoining crawl space; SOG = slab on grade.

[3] Measurement methods: ATD = 3- to 4-month alpha-track detector; CC = 2- to 4-day charcoal detector; Pylon = 2- to 4-day continuous monitor measurement.

Radon results for a given house are listed in order of the date of measurement. Premitigation and post-mitigation results are listed on the same line only if they reflect back-to-back system on/system off measurements.

TABLE 8. RADON REDUCTION PERFORMANCE WITH PASSIVE SOIL DEPRESSURIZATION TECHNIQUES

House No.-Story[1] (Type)[2]	Mit. System[3]	Pre-Mitigation Radon			Post-Mitigation Radon			Estimated % Reduction
		pCi/L	Method[4]	Date	pCi/L	Method	Date	
004 - B	Passive	64.3	CC	<3/87				60 - 80
(B)	SSD +	24.1-24.5	CC	8/87				
	w/f seal	39	Pylon	10/87				
	(Stage 1)				7.8	Pylon	12/87	
					7	Pylon	2/88	
					9.1	ATD	12/87-3/88	
		6.7	Pylon	6/88	2.5	Pylon	6/88	
					6.7-6.8	ATD	3-6/88	
004 -LA	"	37.5	CC	<3/87				0 - 70
		25	Pylon	10/87				
					13.1	Pylon	12/87	
					8	Pylon	2/88	
					8.2-9.1	ATD	12/87-3/88	
		0.7	Pylon	6/88	1.4	Pylon	6/88	
					3.8-3.9	ATD	3-6/88	
008 - B	Passive	64.9	CC	<3/87				30 - 75
(B+SOG)	SSD	11.9-12.5	CC	8/87				
	(Stage 1)	8.3	Pylon	1/88				
					3.3	Pylon	4/88	
					4.5-6.0	ATD	8-11/88	
		11.8	Pylon	11/88	3.0	Pylon	11/88	
008 -LA	"	5.3	Pylon	1/88				30 - 60
					1.8	Pylon	4/88	
					2.7-3.5	ATD	8-11/88	
		3.8	Pylon	11/88	1.8	Pylon	11/88	
032 - B	Passive	11.5	CC	<3/87				30 - 40
(B)	SSD	7.8-7.9	CC	8/87				
	(Stage 1)	11.9	Pylon	12/87				
					3.8	Pylon	4/88	
		10.4	Pylon	6/88	7.1	Pylon	6/88	
					7.2-9.0	ATD	6-9/88	
					7.3-8.4	ATD	9-12/88	
					5.7	Pylon	12/88	
032 -LA	"	6.4	CC	<3/87				0 - 60
		10.9	Pylon	12/87				
					3.1	Pylon	4/88	
		3.4	Pylon	6/88	2.2	Pylon	6/88	
					5.3-6.0	ATD	6-9/88	
					5.3-6.0	ATD	9-12/88	
					4.7	Pylon	12/88	

(continued)

TABLE 8. RADON REDUCTION PERFORMANCE WITH PASSIVE SOIL DEPRESSURIZATION TECHNIQUES (Continued)

House No.-Story[1] (Type)[2]	Mit. System[3]	Pre-Mitigation Radon			Post-Mitigation Radon			Estimated % Reduction
		pCi/L	Method[4]	Date	pCi/L	Method	Date	
047 - B	Passive	11.1	CC	<3/87				20 - 70
(B+CS)	sub-liner	3.2-14.3	CC	8/87				
	depress.	6.5	Pylon	10/87				
	(CS) +				2.5	Pylon	12/87	
	sealing (B)				2.6-3.2	ATD	12/87-3/88	
	(Stage 1)				1.5-1.9	ATD	3-6/88	
		2.6	Pylon	6/88	2.1	Pylon	6/88	
					1.3-1.3	ATD	6-9/88	
					2.4-3.0	ATD	9/88-1/89	
					2.3-2.4	ATD	1-4/89	
047 -LA	"	No pre-mitigation LA data						Unknown
					1.4-1.7	ATD	12/87-3/88	
					0.8-1.4	ATD	3-6/88	
					0.5-0.8	ATD	6-9/88	
					1.5-1.6	ATD	9/88-1/89	
					0.7-1.3	ATD	1-4/89	
054 - B	Passive	23.2	CC	<3/87				0 - 40
(B+CS)	SSD +	10.2-12.2	CC	8/87				
	natural	12.4	Pylon	12/87				
	CS vent				13.5	Pylon	3/88	
	(Stage 1)	9.9	Pylon	6/88	5.9	Pylon	6/88	
054 -LA	"	No pre-mitigation LA data			No post-mitigation LA data			Unknown
061 - B	Passive	12.0	CC	<3/87				20 - 50
(B)	DTD	11.4-14.5	CC	8/87				
	(Stage 1)	9.1-12.3	Pylon	12/87				
					5.7-6.9	Pylon	4/88	
					4.4-7.0	ATD	8-11/88	
		9.2	Pylon	11/88	7.0	Pylon	11/88	
061 -LA	"				3.8-3.8	ATD	8-11/88	About 15
		7.7	Pylon	11/88	6.5	Pylon	11/88	
069 - B	Passive	20.0	CC	<3/87				40 - 70
(B+CS)	SSD +	9.4-9.8	CC	8/87				
	natural	13.2	Pylon	11/87				
	CS vent				7.2	Pylon	1/88	
	(Stage 1)				5.2-5.5	ATD	2-5/88	
		14.7	Pylon	6/88	4.8	Pylon	6/88	
					3.8-5.1	ATD	5-8/88	
069 -LA	"	13.2	CC	<3/87				50 - 75
		8.5	Pylon	11/87				
					4.3	Pylon	1/88	
					2.7-2.8	ATD	2-5/88	
		7.0	Pylon	6/88	1.7	Pylon	6/88	
					2.7-3.5	ATD	5-8/88	

(continued)

TABLE 8. RADON REDUCTION PERFORMANCE WITH PASSIVE SOIL DEPRESSURIZATION TECHNIQUES (Continued)

House No.- Story[1] (Type)[2]	Mit. System[3]	Pre-Mitigation Radon			Post-Mitigation Radon			Estimated % Reduction
		pCi/L	Method[4]	Date	pCi/L	Method	Date	
069 - B (B+CS)	Improved passive SSD + passive BWD (Stage 2)	Pre-mit. levels shown above for basement						15 - 75
					3.4	Pylon	7/88	
					10.9	Pylon	11/88	
					8.2-11.3	ATD	8-12/88	
069 -LA	"	Pre-mit. levels shown above for living area						40 - 60
					2.7	Pylon	7/88	
					5.3	Pylon	11/88	
					6.1-6.6	ATD	8-12/88	
074 - B (B+CS)	Passive SSD (B)+ passive SLD (CS) (Stage 1)	27.8	CC	<3/87				0 - 30
		7.6	CC	8/87				
		16.2	Pylon	1/88				
					10.7-11.6	Pylon	4/88	
		11.4-13.1	Pylon	1/89				
074 -LA	"	13.0	CC	<3/87				Unknown
					No post-mitigation LA data			
076 - B (B+CS)	Passive SSD (B) + CS isolation (Stage 1)	16.8	CC	<3/87				0 - 80
		4.3-7.9	CC	8/87				
		9.5	Pylon	1/88				
					3.0	Pylon	4/88	
					9.7-9.8	ATD	8-11/88	
		14.2	Pylon	11/88	2.8	Pylon	11/88	
076 -LA	"	4.3	Pylon	1/88				30 - 80
					0.8	Pylon	4/88	
					2.7-3.4	ATD	8-11/88	
		4.7	Pylon	11/88	0.9	Pylon	11/88	
079 - B (B)	Passive SSD (Stage 1)	20.2	CC	<3/87				70 - 90
		12.4-12.5	CC	8/87				
		17.2-20.5	CC	1/88				
		17.3-24.0	Pylon	1/88				
		2.8-3.0	Pylon	4/88	0.7-0.8	Pylon	4/88	
		3.1-2.4	Pylon	5/88	0.8-0.9	Pylon	5/88	
					1.9-2.1	ATD	6-9/88	
					2.2-2.6	ATD	9-12/88	
					0.6	Pylon	12/88	
079 -LA	"	10.6	CC	<3/87				80 - 90
					1.3-1.4	ATD	6-9/88	
					2.0 (est)	ATD	9-12/88	
					0.3	Pylon	12/88	

(continued)

TABLE 8. RADON REDUCTION PERFORMANCE WITH PASSIVE SOIL DEPRESSURIZATION TECHNIQUES (Continued)

House No.-Story[1] (Type)[2]	Mit. System[3]	Pre-Mitigation Radon			Post-Mitigation Radon			Estimated % Reduction
		pCi/L	Method[4]	Date	pCi/L	Method	Date	
096 - B	Passive	16.2-17.0	CC	8/87				35 - 75
(B+SOG)	DTD (B)	23.0	Pylon	10/87				
	+ passive				4.4	Pylon	11/87	
	SSD (SOG)				6.6-8.6	ATD	12/87-3/88	
	(Stage 1)				4.8-4.9	ATD	3-6/88	
		6.9	Pylon	7/88	4.3	Pylon	7/88	
					1.9-3.9	Pylon	7/88	
					4.0-4.5	ATD	6-9/88	
096 -LA	"	15.7	CC	<3/87				25 - 90
		4.3	Pylon	10/87				
					2.5	Pylon	11/87	
					2.6-4.8	ATD	12/87-3/88	
					1.8-2.3	ATD	3-6/88	
		3.2	Pylon	7/88	2.3	Pylon	7/88	
					2.7-4.6	Pylon	7/88	
					1.4-2.0	ATD	6-9/88	
					1.0	Pylon	12/88	
106 - B	Passive	19.2	CC	<3/87				0 - 50
(B+SOG)	SSD (B)	14.1-14.4	CC	8/87				
	+ sealing	58	Pylon	2/88				
	(Stage 1)	21	Pylon	3/88	10	Pylon	3/88	
					15.2	Pylon	5/88	
106 -LA	"	7.1	CC	<3/87				About 50
		18	Pylon	2/88				
		10	Pylon	3/88	5	Pylon	3/88	
106 - B	Passive	19.2	CC	<3/87				40 - 85
	SSD +	14.1-14.4	CC	8/87				
	passive	58	Pylon	2/88				
	BWD (B)	21	Pylon	3/88				
	(Stage 2)				8.3-8.6	ATD	8-11/88	
					7.1	Pylon	11/88	
106 -LA	"	7.1	CC	<3/87				30 - 80
		18	Pylon	2/88				
		10	Pylon	3/88				
					4.1-5.7	ATD	8-11/88	
					4.1	Pylon	11/88	

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[1] The story on which the reported measurements were obtained: B = basement; LA = living area.

[2] House types: B = basement; B+SOG = basement with adjoining slab on grade; B+CS = basement with adjoining crawl space; SOG = slab on grade.

[3] Mitigation systems: SSD = sub-slab depressurization (vertical pipes through slab); DTD = drain tile depressurization (suction on sump); BWD = block wall depressurization; SLD = sub-liner depressurization in crawl space.

[4] Measurement methods: ATD = 3- to 4-month alpha-track detector; CC = 2- to 4-day charcoal detector; Pylon = 2- to 4-day continuous monitor measurement.

TABLE 9. RADON REDUCTION PERFORMANCE WITH ACTIVE SOIL DEPRESSURIZATION TECHNIQUES

House No.-Story[1] (Type)[2]	Mit. System[3]	Pre-Mitigation Radon pCi/L	Pre-Mitigation Radon Method[4]	Pre-Mitigation Radon Date	Post-Mitigation Radon pCi/L	Post-Mitigation Radon Method	Post-Mitigation Radon Date	Estimated % Reduction
004 - B (B)	Active SSD (Stage 2)	6.7-64.3[5] 11.7	All[5] Pylon	<3/87-6/88 1/89	0.8-0.9 0.4 0.4-0.5	ATD Pylon ATD	9/88-1/89 1/89 1-4/89	92 - 99
004 -LA	"	0.7-37.5[5] 6.7	All Pylon	<3/87-6/88 1/89	1.4-2.0 0.2 <0.3-0.4	ATD Pylon ATD	9/88-1/89 1/89 1-4/89	92 - 99
008 - B (B+SOG)	Active SSD + active DTD (B) (Stage 2)	8.3-64.9[5] 0.4[6]	All Pylon	<3/87-11/88 1/89	0.2 1.1-1.2	Pylon ATD	1/89 11/88-2/89	85 - 99
008 -LA	"	3.8-5.3[5] 0.4[6]	Pylon Pylon	1-11/88 1/89	0.1 0.4-0.5	Pylon ATD	1/89 11/88-2/89	87 - 98
010 - B (B)	Active DTD (Stage 3)	6.8-17.6[5] 8.5	All Pylon	<3/87-11/87 1/89	0.3	Pylon	1/89	50 - 98
010 -LA	"	2.3-11.8[5] 3.9	All Pylon	<3/87-11/87 1/89	0.2	Pylon	1/89	10 - 98
011 - B (B+SOG)	Active SSD (B) + active SSD (SOG) (Stage 1)	135-178 88.3	CC Pylon	<3/87 11/87	0.1 0.1 0.6-1.2 3.0-3.5[7] 0.5-3.2[7] 1.8-1.9	Pylon Pylon ATD ATD ATD ATD	12/87 12/87 12/87-3/88 3-6/88 6-9/88 9/88-1/89	96 - 99+
011 -LA	"	43.1	Pylon	11/87	0.5 1.3-2.2 7.9-8.6[7] 1.0-1.0[7] 3.1-3.1	Pylon ATD ATD ATD ATD	12/87 12/87-3/88 3-6/88 6-9/88 9/88-1/89	93 - 99
032 - B (B)	Active SSD (Stage 2)	7.8-11.9[5] 3.8	All Pylon	<3/87-6/88 12/88	0.7 1.1-1.4	Pylon ATD	12/88 12/88-3/89	82 - 90
032 -LA	"	3.4-10.9[5] 3.7	All Pylon	<3/87-6/88 12/88	1.3 1.2-1.2	Pylon ATD	12/88 12/88-3/89	65 - 89

(continued)

TABLE 9. RADON REDUCTION PERFORMANCE WITH ACTIVE SOIL DEPRESSURIZATION TECHNIQUES (Continued)

House No.- Story[1] (Type)[2]	Mit. System[3]	Pre-Mitigation Radon			Post-Mitigation Radon			Estimated % Reduction
		pCi/L	Method[4]	Date	pCi/L	Method	Date	
041 - B	Active	265.2	CC	<3/87				
(B+SOG)	SSD (B)	298	Pylon	11/87				94 - 99+
	+ active	22.7	Pylon	1/88				
	SSD (SOG)				0.6	Pylon	1/88	
	(Stage 1)				1.3-1.4	ATD	2-5/88	
					1.1-1.6[7]	ATD	5-8/88	
					0.4-0.7	ATD	1-4/89	
041 -LA	"	231.6	CC	<3/87				
		222	Pylon	11/87				95 - 99+
		24.5	Pylon	1/88				
					0.9-1.2	ATD	2-5/88	
					0.9-1.4[7]	ATD	5-8/88	
					0.5-0.6	ATD	1-4/89	
054 - B	Active	9.9-23.2[5]	All	<3/87-6/88				
(B+CS)	SSD (B)	14.8	Pylon	7/88	1.6	Pylon	7/88	50 - 90
	(Stage 2)				5.7-6.5	ATD	7-11/88	
		33.4	Pylon	1/89	16.0	Pylon	1/89	
		21.0	Pylon	1/89	8.8	Pylon	1/89	
					8.9-10.8	ATD	11/88-2/89	
054 -LA	"	No pre-mitigation LA data			No post-mitigation LA data			Unknown
061 - B	Active	9.1-14.5[5]	All	<3/87-11/88				Over 90
(B)	DTD	5.9	Pylon	12/88-1/89	0.4	Pylon	1/89	
	(Stage 2)							
061 -LA	"	7.7	Pylon	11/88				Over 90
		5.2	Pylon	12/88-1/89	0.4	Pylon	1/89	
069 - B	Active	9.4-20.0[5]	All	<3/87-6/88				87 - 99
(B+CS)	SSD +	9.8	Pylon	1/89	0.8	Pylon	1/89	
	BWD	11.6	Pylon	1/89	0.2	Pylon	1/89	
	(Stage 3)				1.0-1.3	ATD	12/88-3/89	
069 -LA	"	7.0-13.2[5]	All	<3/87-6/88				77 - 98
		6.8	Pylon	1/89	0.3	Pylon	1/89	
		5.6	Pylon	1/89	0.4	Pylon	1/89	
					1.0-1.3	ATD	12/88-3/89	
074 - B	Active	7.6-27.8[5]	All	<3/87-1/89				20 - 85
(B+CS)	SSD (B) +				3.8-4.1	ATD	8-12/88	
	SLD (CS)	11.4	Pylon	1/89	6.0	Pylon	1/89	
	(Stage 2)				4.4-6.0	ATD	12/88-3/89	
074 -LA	"	13.0	CC	<3/87				About 70
					2.5-2.8	ATD	8-12/88	
					3.9-4.2	ATD	12/88-3/89	

(continued)

TABLE 9. RADON REDUCTION PERFORMANCE WITH ACTIVE SOIL DEPRESSURIZATION TECHNIQUES (Continued)

House No.-Story^{1} (Type)^{2}	Mit. System^{3}	Pre-Mitigation Radon			Post-Mitigation Radon			Estimated % Reduction
		pCi/L	Method^{4}	Date	pCi/L	Method	Date	
076 - B (B+CS)	Active SSD (Stage 2)	4.3-16.8^{5} 8.9	All Pylon	<3/87-11/88 12/88-1/89	0.5 1.2-2.9	Pylon ATD	1/89 11/88-2/89	70 - 97
076 -LA	"	4.3-4.7^{5} 4.5	Pylon Pylon	1-11/88 12/88-1/89	0.6 0.7-0.7	Pylon ATD	1/89 11/88-2/89	About 85
079 - B (B)	Active SSD (Stage 2)	2.8-24.0^{5} 0.8^{6}	All Pylon	<3/87-5/88 1/89	0.4 0.4-0.9	Pylon ATD	1-2/89 12/88-3/89	95 - 98
079 -LA	"	10.6^{5} 0.7^{6}	CC Pylon	<3/87 1/89	<0.1 0.6-1.1	Pylon ATD	1-2/89 12/88-3/89	90 - 99
096 - B (B+SOG)	Active SSD (B) + active SSD (SOG) (Stage 2)	6.9-23.0^{5} 7.0	All Pylon	8/87-7/88 1/89	0.5 0.6-0.7	Pylon ATD	1/89 1-4/89	90 - 98
096 -LA	"	3.2-15.7^{5} 2.2	All Pylon	<3/87-7/88 1/89	0.4 <0.3-0.5	Pylon ATD	1/89 1-4/89	80 - 99
106 - B (B+SOG)	Active SSD + BWD (B) (Stage 3)	14.1-58^{5} 10.3 7.9	All Pylon Pylon	<3/87-3/88 1/89 1/89	0.1 <0.1	Pylon Pylon	1/89 1/89	99
106 -LA	"	7.1-18^{5} 3.2	All Pylon	<3/87-3/88 1/89	<0.1	Pylon	1/89	>97
110 -LA (SOG)	Active SSD (Stage 1)	30.9-31.0 11.4-12.7 26.2 23.8 22.9-24.8 11.6-12.6	CC CC Pylon Pylon Pylon Pylon	<3/87 8/87 1/88 3/88 4/88 5/88	0.1 0.5-0.9 0.6-0.7 0.8-1.2 0.6-1.1	Pylon Pylon ATD ATD ATD	4/88 5/88 5-9/88 9/88-1/89 1-4/89	92 - 99
126 - B (B)	Active SSD + DTD (Stage 1)	44.7 44.9-46.2 55.8 5.8-30.7	CC CC Pylon Pylon	<3/87 8/87 4/88 5/88	1.2 0.5-0.7 1.2-1.9 1.4-1.9 0.6-0.7	Pylon Pylon ATD ATD ATD	4/88 5/88 5-9/88 9/88-1/89 1-4/89	96 - 98
126 -LA	"	No data						Unknown

(continued)

TABLE 9. RADON REDUCTION PERFORMANCE WITH ACTIVE SOIL DEPRESSURIZATION TECHNIQUES (Continued)

House No.- Story[1] (Type)[2]	Mit. System[3]	Pre-Mitigation Radon			Post-Mitigation Radon			Estimated % Reduction
		pCi/L	Method[4]	Date	pCi/L	Method	Date	
143 - B	Active	71	Pylon	11/87				
(B)	SSD	52.6	Pylon	1/88				93 - 97
	(Stage 1)				1.6	Pylon	1/88	
					1.6-1.7	ATD	2-5/88	
		1.2[6]	Pylon	7/88	1.1	Pylon	7/88	
					1.6-1.7	ATD	5-8/88	
					1.7-2.6	ATD	8-12/88	
					3.3-3.5	ATD	12/88-3/89	
143 -LA	"	46.8-57.2	CC	<3/87				
		36.8	Pylon	11/87				92 - 95
		27.3	Pylon	1/88				
					1.3	Pylon	1/88	
					1.1-1.4	ATD	2-5/88	
		1.2[6]	Pylon	7/88	1.3	Pylon	7/88	
					1.4-1.6	ATD	5-8/88	
					2.7-2.8	ATD	8-12/88	
					2.3	ATD	12/88-3/89	
163 - B	Active	19.1	CC	<3/87				
(B+CS)	SSD (B)	31.0	Pylon	12/87				75 - 95
	+ active							
	SLD (CS)	2.6[6]	Pylon	7/88	0.8	Pylon	3/88	
	(Stage 1)				1.0[7]	Pylon	7/88	
					0.6-1.4[7]	ATD	7-11/88	
					1.6-4.8[7]	ATD	11/88-2/89	
163 -LA	"	13.1	CC	<3/87				
		18.5	Pylon	12/87				92 - 98
		2.0[6]	Pylon	7/88	<0.1	Pylon	3/88	
					0.6[7]	Pylon	7/88	
					0.7-1.6[7]	ATD	7-11/88	
					>0.3-1.0[7]	ATD	11/88-2/89	

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[1] The story on which the reported measurements were obtained: B = basement; LA = living area.

[2] House types: B = basement; B+SOG = basement with adjoining slab on grade; B+CS = basement with adjoining crawl space; SOG = slab on grade.

[3] Mitigation systems: SSD = sub-slab depressurization (vertical pipes through slab); DTD = drain tile depressurization (suction on sump); BWD = block wall depressurization; SLD = sub-liner depressurization in crawl space.

[4] Measurement methods: ATD = 3- to 4-month alpha-track detector; CC = 2- to 4-day charcoal detector; Pylon = 2- to 4-day continuous monitor measurement.

[5] Range of individual pre-mitigation radon measurements; the individual measurements for this house were reported previously in Table 8.

[6] Radon measurement in house with mitigation fan turned off, made immediately after fan had been operating for an extended period. When the fan is turned off, there appears to be an extended delay (of at least several days) in the recovery of indoor radon concentrations to their original pre-mitigation levels; thus, this low measurement is probably not representative of what non-mitigated levels would be after full recovery.

[7] Active SSD fan at reduced power during part or all of this measurement.

CHAPTER 7

RESULTS WITH ENTRY ROUTE SEALING

7.1 INTRODUCTION

Entry routes are openings through the house shell through which radon gas can move into the house from the underlying soil. Typical entry routes include, for example: cold joints and settling cracks in basement slabs; the joint between the slab and the foundation wall (the floor/wall joint); untrapped floor drains which connect to the soil (e.g., which drain to drain tiles or to a dry well); sump holes which connect to the soil (e.g., via drain tiles or via exposed soil in the hole); uncapped top blocks in a block foundation wall; and unpaved crawl spaces which open to the living area.

Some potentially major entry routes, such as sump pits, can usually be fairly easily accessed for sealing. Others -- such as hairline slab cracks, pores in the block foundation wall, etc. -- are difficult to seal because they can be numerous and sometimes inaccessible (e.g., behind floor or wall finish). These other entry routes, although small, can cumulatively provide a significant pathway for radon into the house. Even when entry routes can be accessed, it can be very difficult to create a permanent and truly gas-tight seal. Because of this difficulty in accessing and effectively sealing all entry routes, efforts to reduce radon levels using sealing alone have commonly resulted in only limited radon reductions, if any.

In this project, one house (House 010) was selected for a test of sealing by itself as a mitigation method. The objective was to demonstrate whether sealing alone might offer potential for achieving at least limited reductions (suitable for houses with only slightly elevated radon levels) in cases where most major entry routes appear to be accessible.

It should be noted that some degree of sealing is necessary even in houses where the primary mitigation method is soil depressurization. In that case, the primary objective of the sealing is to reduce the amount of house air that would leak down through the entry routes into the depressurization system. Large amounts of house air leakage could: a) reduce the extension of the system's suction field, thus reducing system performance; and b) increase the house heating and cooling costs. When sealing in conjunction with a soil depressurization system, it is not necessary to achieve an essentially total seal on essentially all entry routes; the soil depressurization system should be able to handle any remaining unsealed routes. But where sealing is a stand-alone mitigation method, very effective closure of almost all entry routes will probably be necessary to provide any significant radon reduction.

7.2 DESCRIPTION OF SEALING METHODS

House 010 was a promising candidate for this method because it was a "pure" basement house (with no adjoining slab-on-grade or crawlspace wing), and the basement was unfinished, so that all apparent entry routes were easily accessible. Also, all four hollow concrete block basement walls had capped top blocks, and the exterior of the block walls had tar waterproofing, which may have limited the amount of soil gas penetrating through the walls. In addition, the pre-mitigation radon levels appeared to be only slightly elevated (2.3 pCi/L in the living room and 6.8 pCi/L in the basement, according to the pre-mitigation Pylon measurement in November 1987), so that only moderate radon reductions were needed. This house would have been even a better candidate for this method if it had poured concrete basement walls rather than hollow block walls.

Stage 1. During Stage 1, the basement floor/wall joint was ground out with a hand-held grinder and sealed with flowable (self-leveling) polyurethane caulk. Some interior slab cracks were also routed and filled with non-flowable urethane caulk with a layer of flowable caulk on top. Several cracks, gaps, holes, and penetrations in the block walls were sealed with non-flowable polyurethane and expandable foam. The sump, which was connected to a drain tile loop around the interior of the footings, was sealed by installing a pre-fabricated plastic cover, which was bolted to the slab with a seal of urethane caulk; the sump was passively vented to the outdoors via the pump discharge pipe through the basement wall. An untrapped floor drain and the air conditioner condensate drain drained into the sump; to prevent soil gas in the sump from flowing into the basement through these drains, the ends of these drain lines were immersed in a container of water on the bottom of the sump pit. To help reduce the depressurization of the basement by the central forced-air furnace cold air return ducts in the basement, the joints between sections of the ducting were taped. Thus, it appeared that all of the existing radon gas entry routes had been sealed, except for the basement side of the hollow block basement walls. The walls were not painted with a sealant in Stage 1 because this is usually a time-consuming step, and it was desired to see if radon levels could be appreciably reduced without it. Because the quality of the tar waterproofing application to the block basement wall exterior was not known, the pores and remaining cracks in the block walls may still have been a source of radon gas infiltration. Also, radon may have bypassed the tar-treated wall by seeping into the interior side of the block walls between the footer and the slab joint.

Stage 2. As discussed later, radon levels did not appear to be appreciably reduced by the sealing steps taken during Stage 1. Measurements following the Stage 1 effort showed that the radon level in one of the basement block walls was 29.6 pCi/L, indicating that the block wall pores and cracks could be a radon source. Thus, in Stage 2, the four basement block walls were painted with waterproofing sealant. However, subsequent inspection showed that the waterproofing sealant was readily absorbed into the block wall pores and did not provide a gas-tight seal.

7.3 RESULTS

The results of the sealing tests in House 010, presented in detail in Table 7, are summarized in Table 10.

TABLE 10. ENTRY ROUTE SEALING RESULTS

House	Stage	Location	Radon Levels (pCi/L) Before	Radon Levels (pCi/L) After	% Reduction
010	1	Basement	6.8-17.6	4.4-10.0	0 - 40
	1	Living area	2.3-11.8	4.2	Limited
010	2	Basement	6.8-17.6	7.9-10.4	0 - 40
	2	Living area	2.3-11.8	4.7- 5.0	0 - 50

Assessment of these results is complicated by the fact that so much time unavoidably passed between pre- and post-mitigation measurements, and weather conditions varied. Pre-mitigation radon levels of 6.8 pCi/L in the basement and 2.3 pCi/L in the living room were measured with the Pylon over two days in November 1987 during mild weather with a daytime temperature range of 65 to 70°F. Earlier charcoal detector measurements by the homeowner, in the Fall of 1986 (weather conditions uncertain), gave pre-mitigation readings of 17.6 pCi/L in the basement and 11.8 pCi/L upstairs.

Following the Stage 1 sealing, basement radon levels measured for four days each in January, March, and May 1988 were 10.0, 4.4 and 9.8 pCi/L, respectively. Also, a spring-time basement radon level for a three-month period measured with alpha-track detectors was 7.3 pCi/L. Thus, although it was not possible to conduct unambiguous, back-to-back "system on/off" measurements with this mitigation approach, it is apparent that -- if there was any radon reduction in the basement resulting from Stage 1 -- it was probably no greater than 40%. The only post-mitigation measurement completed upstairs after Stage 1 was with the spring alpha-track; this mild weather reading was 4.2 pCi/L, suggesting that the radon reduction in the living area was also zero to moderate, as would be expected.

After the basement wall was painted for Stage 2, it is clear from Table 10 that no further radon reductions were achieved. Reductions both in the basement and upstairs remained zero to moderate. This could have been due to the fact that the pores and cracks in the wall had not been completely sealed by the water-proofing paint, as mentioned previously.

7.4 COSTS

The total cost to complete the radon gas entry route sealing effort at House 010, including sealing the block wall pores, was $1,440.

CHAPTER 8

SUB-SLAB DEPRESSURIZATION

8.1 INTRODUCTION

Soil depressurization is one of the most common radon reduction techniques used by radon remediation professionals. There are several variations of soil depressurization: sub-slab depressurization (SSD); sump/drain tile depressurization (DTD); block wall depressurization (BWD); and, in crawl spaces, sub-liner depressurization (SLD). All four of these methods -- alone and in various combinations -- were tested during this project. This chapter addresses those houses where SSD was tested by itself. Subsequent chapters address: DTD by itself; SLD by itself; and various combinations.

A typical active (fan-assisted) SSD system is shown in Figure 1. As defined here, SSD involves one or more suction pipes inserted into the sub-slab region, either vertically down through the slab from indoors, or horizontally through the foundation wall (below slab level) from outdoors. These pipes are then connected to a fan which draws suction on the pipes (active SSD), or to a passive stack that rises up through the house and out the roof, without a fan (passive SSD).

Passive SSD relies upon natural phenomena to create the suction needed to depressurize the sub-slab. These phenomena include: the natural stack effect created when temperatures indoors are higher than temperatures outdoors; and suction created by winds passing over the roofline. In one SSD case in this study, an effort was made to increase the passive suction by using the furnace flue as

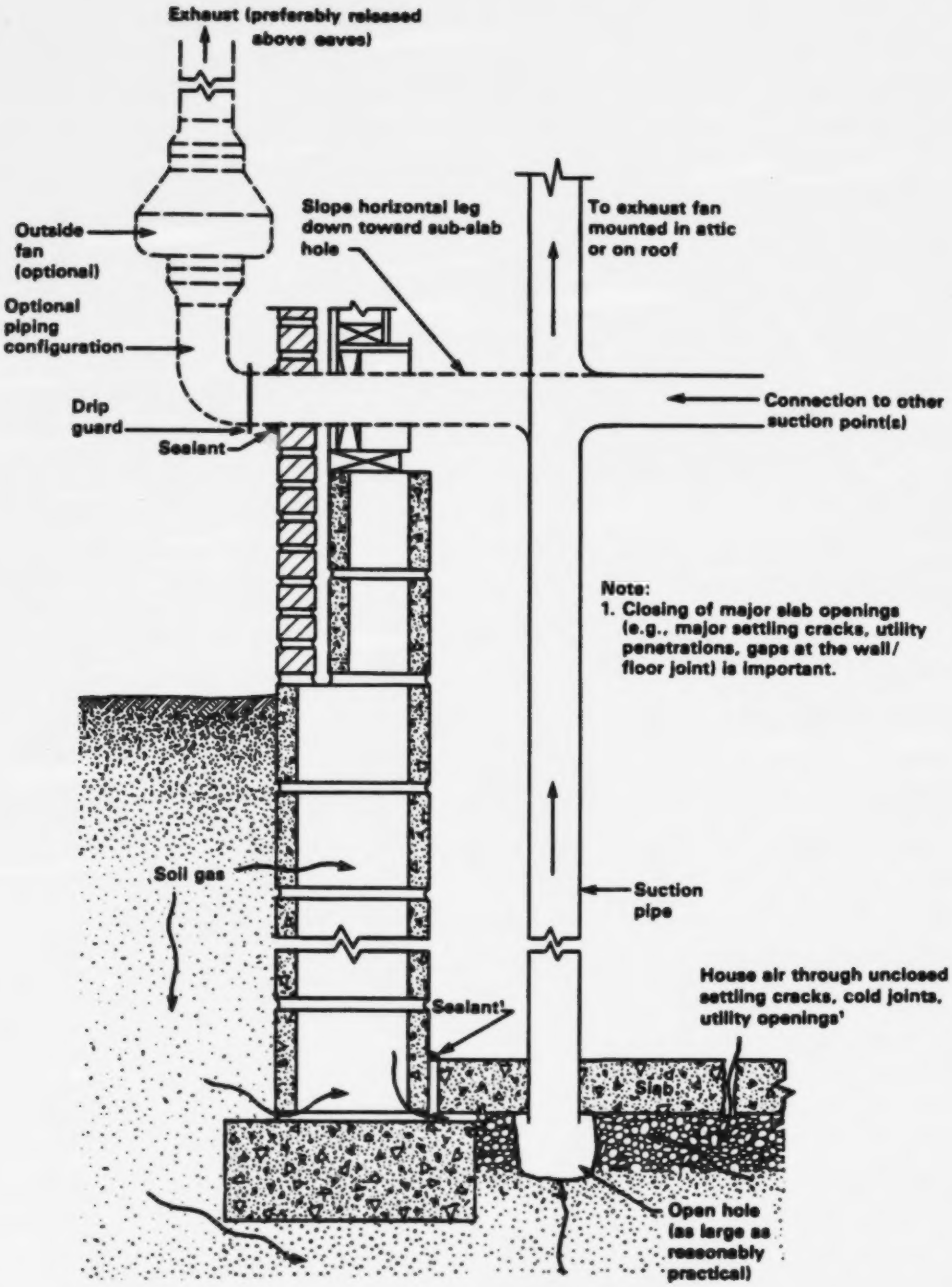

Exhaust (preferably released above eaves)
Outside fan (optional)
Optional piping configuration
Drip guard
Sealant
Slope horizontal leg down toward sub-slab hole
To exhaust fan mounted in attic or on roof
Connection to other suction point(s)
Note:
1. Closing of major slab openings (e.g., major settling cracks, utility penetrations, gaps at the wall/floor joint) is important.
Soil gas
Suction pipe
Sealant¹
House air through unclosed settling cracks, cold joints, utility openings¹
Slab
Open hole (as large as reasonably practical)

Figure 1. Sub-Slab Depressurization

Source: Reference 2

the passive stack; hot furnace combustion products flowing up the flue in cold weather would increase the stack suction. Because the suctions which can be naturally induced in passive stacks are usually fairly low (generally lower than 0.1 in. WG) and can vary with temperature and wind conditions, most commercial mitigators utilize active systems, where the system fan generates suction commonly an order of magnitude greater than that in passive stacks, and high radon reductions can more confidently and consistently be achieved.

As a result of this preference for active systems, little data have been generated on the performance of passive systems. However, if they can be shown to reliably achieve some moderate radon reductions -- or perhaps high reductions under the right set of circumstances -- then passive systems might be attractive under certain conditions. If they can be used with confidence, passive systems offer certain advantages over active systems; in particular, the need for continued maintenance to a system fan is avoided, along with any fan noise and with the increased house heating and cooling costs likely to be created by the relatively larger amounts of house air exhausted by the active SSD fan.

A primary objective of this study was to assess the performance of passive soil ventilation systems retrofit into existing houses. (Passive systems might offer greater potential in new construction, where provisions can be made during the construction process to improve the potential performance of the passive system.) Accordingly, passive SSD systems by themselves (not in conjunction with any other soil depressurization method) were initially installed in the basement in eight of the houses under this project. These eight houses included two which were pure basements, three which were basements with adjoining slabs on grade, and three which were basements with adjoining crawl spaces. In all cases, the passive SSD system treated just the basement, although increased natural ventilation and isolation of the crawl space, as well as sealing of potential basement entry routes, were often included as part of the passive installation. (All of these eight houses were ultimately converted to some form of active system in later stages of the project.)

Active SSD by itself was tested in nine of the houses. Four of these houses (Houses 011, 041, 110, and 143) received the active system immediately, in Stage 1; this occurred either because the pre-mitigation radon levels were so elevated that the passive approach was not considered appropriate, or because sub-slab communication appeared too poor to offer hope for success of a passive system. The other five active SSD houses were houses which had initially received a passive SSD system which was activated during a later test stage. Of the four houses which received active SSD systems immediately in Stage 1, two were basements with adjoining slabs-on-grade, one was a pure basement, and one was a pure slab on grade. The two basements having an adjoining slab (House 011 and 041) received active SSD systems treating both the basement slab and the adjoining slab.

Between these eight passive and nine active installations, "pure" SSD was tested in 12 different houses.

8.2 INSTALLATION TECHNIQUES

Locations of sub-slab suction holes varied in the 12 houses in which either passive or active SSD was used, depending on the characteristics of each house. House 004 had a large rectangular basement and received two suction holes, one on each end near the foundation wall; the vertical 4-in. suction pipes penetrating the slab at those two points were manifolded together with 4-in. piping to a single 6-in. stack that went up through the house (initially passive, with a fan added in Stage 2). Only one vertical suction pipe was inserted through the slab, at a point near a perimeter wall, in the basements of houses 008, 054, 076, 079, 106, and 143, located. The sub-slab soil is likely to have a higher permeability near foundation walls, since it is known that this area had to be excavated for footings; the fill soil in that area may be more loosely-packed, or may even have settled down below the bottom of the slab, leaving an air gap. These locations were also near the floor/wall joints and foundation walls, facilitating better control of these potentially important entry routes. Additional reasons for selecting the perimeter location in specific houses were: to be near the central furnace in House 076, so that the furnace flue could be used as a passive stack; to utilize an unused sump pit (no drain tiles) in House 079, as a ready-made hole through the slab; and to be near the four-flue chimney in House 106, so that one of the unused flues could be utilized as a passive stack.

In Houses 032 and 069, a single vertical suction pipe was installed in the center of each basement slab; good suction field extension would be required for the passive systems to effectively treat the floor/wall joints and foundation walls in these houses. In Houses 011 and 041 (both receiving active SSD systems), two vertical suction pipes were inserted down through the basement slab near the stem wall separating these basements from the adjoining slabs on grade; a horizontal leg tapping off each of these vertical pipes penetrated the stem wall below the adjoining slab, to provide suction under the adjoining slab. At House 110 -- which was a slab-on-grade house having three separately-poured slabs -- three active suction pipes were used, one below each of the three distinct slabs, penetrating horizontally through the foundation wall from outdoors.

Four different methods were used to access the sub-slab area in the 12 houses. The choice of which method was appropriate for a house was based on house features and on the communication under the slab. The techniques included: 1) drilling a 4-1/2 inch or 6-1/2 inch diameter hole through the slab for the suction pipe, and performing only limited excavation under the hole (used when communication was reasonably good); 2) jackhammering a 2-foot by 2-foot hole in the slab, to enable excavation of a larger pit under the suction pipe (used to improve suction field extension when communication was poor); 3) drilling a hole horizontally through the foundation wall below slab level from outside the house (or, in the case of adjoining slabs on grade, through the stem wall from inside the basement); and 4) using an existing sump pit (when an unused sump pit with no drain tiles provided a ready-made hole through the slab). These techniques are described below.

At Houses 008, 011, 041, 054, 069, 076, 106 and 143, reasonably good sub-slab communication was expected, as a result of pre-mitigation diagnostic tests and/or information provided by the homeowners. In these cases, it was not thought to be necessary to try to improve suction field extension by excavating large sub-slab holes underneath the suction pipes. For these houses, the sub-slab access holes were made simply by drilling 4-1/2 inch or 6-1/2 inch diameter holes through the slabs to accommodate 4-inch or 6-inch suction pipes. Sub-slab soil was removed from the holes to the extent possible to decrease the pressure losses caused by accelerating the soil gas from zero velocity up to the flow rate in the suction pipe. (Pressure drops normally occur when soil gas accelerates through sub-slab material.) The 4-inch or 6-inch PVC suction pipes were inserted into the slab holes to a depth such that the bottom of the pipe was even with the bottom of the slab. The concrete around perimeters of the cored holes was chipped out to provide a channel so that the seam between the pipe wall and the slab could be sealed with flowable polyurethane. At Houses 011 and 041, it was also necessary to drill holes horizontally through the stem walls in the basements to access the area below the slab-on-grade portion of the house.

When sub-slab permeability was believed to be poor, 2-foot by 2-foot holes were made in the slab so that greater amounts of sub-slab material could be removed. A hand-held grinder was used to cut a 1/2-inch deep channel in the slab outlining the perimeter of the 2-foot by 2-foot holes. A jackhammer was then used to break out the concrete. This method was used at House 004. This technique was also used at House 032 where a 6-1/2 inch diameter hole had initially been drilled. Because no aggregate was observed in the hole, the hole was enlarged to 2-foot by 2-foot. Once these large depressurization holes were created, several smaller holes were drilled into the soil. The 4-inch or 6-inch suction pipes were placed into the 2-foot by 2-foot, and the pits were filled with aggregate. After a plastic vapor barrier was placed over the aggregate, the holes were filled with non-shrink grout. The joints between the non-shrink grout and the existing slab, and between the suction pipe and the grout, were tooled to create a channel which was then sealed with flowable polyurethane.

In slab-on-grade House 110, the three sub-slab areas were accessed by drilling holes horizontally through the foundation walls below slab level, from outdoors. Sub-slab soil was removed from the three holes to the extent possible, and 2-inch diameter PVC suction pipes were inserted into the holes.

In House 079, an existing unused sump pit (with no drain tiles) was used to access the sub-slab area. This avoided the difficulty of drilling a 4-1/2 inch diameter hole through the slab or the even greater effort required to make a 2-foot by 2-foot slab hole. The bottom of the sump was open to the soil; in addition, to further improve communication between the sump pit and the sub-slab, two break-away pieces in the plastic sump crock (designed to accommodate drain tiles) were removed. A 4-inch PVC suction pipe was inserted, and the sump was sealed with a plywood cover.

Suction pipes used in the 12 sub-slab ventilation systems were either 4-inch or 6-inch PVC pipe. In all of the passive depressurization systems, the suction pipes were routed up through the roof within the houses, as necessary for the system to take advantage of the "stack effect." An effort was made to make these stacks as straight up as possible through the houses, although some bends in the stack were often necessary to achieve an aesthetically acceptable path up through the house. With most of the passive systems, a 12-inch diameter wind turbine was installed on top of the stack, in an effort to improve natural suction. Only in Houses 076 (where the furnace flue was used as the stack) and 106 (where an unused chimney flue was utilized) were turbines not installed.

Active depressurization systems were powered by 270 cfm in-line duct fans with either plastic or metal bodies, capable of developing up to 1.4 in. WG suction at zero flow; however, in House 143, a 179 cfm fan was installed. With some of the active systems, the exhaust pipe was directed outside via the basement band joist. In these cases, the exhaust stack was usually taken up above the eaves outside the house, with the fan mounted on top of the stack; often, the entire exhaust assembly was then enclosed within a framed chase. In a few cases, the owner requested that no stack be installed; for these houses, the fan exhausted horizontally at grade level. In cases where a passive SSD system was being converted to an active system in a later stage, the fan was usually just mounted in the attic on the existing stack up through the house.

In addition to the sub-slab depressurization systems installed in Houses 054 and 069, the natural crawl-space ventilation was increased by installing foundation vents through the crawl-space walls.

Also, some degree of entry route sealing was carried out in all houses except Houses 011 and 143. Where floor/wall joints were not tight, the joint was routed with a hand-held grinder to form a channel which was then filled with flowable polyurethane. In a few of the houses, the floor/wall joints contained expansion material (asphalt-impregnated fiber material); in these cases, a jackhammer was used to compress the expansion material in order to create the necessary channel. Preparing the floor/wall joint in this manner required less time than grinding with a hand-held grinder.

If the voids were open on the top course of blocks in a hollow-block foundation wall, and where the top voids were accessible, they were sealed with expandable foam. Uncapped top blocks in some of the houses were inaccessible for sealing due to finishing or the presence of a sill plate. Openings around pipe penetrations through slabs and exterior walls were sealed if they were sufficiently large. Slab cracks and floor/wall joints were filled with flowable polyurethane caulk. Utility and plumbing pipes that penetrated through the slabs and foundation walls were prepared by chipping out a channel in the concrete around the perimeter. The penetrations through the slabs were sealed with either flowable or non-flowable polyurethane, and the penetrations through the foundation walls were sealed with non-flowable polyurethane. In a few instances, the hollow support posts in basements were sealed by drilling a hole into each post and filling the bottom portion with expandable foam. However, in most of the houses with hollow support posts, no sealing was necessary because the hollow support posts were anchored in solid concrete. Untrapped floor drains connecting to the soil were trapped; if there was not a drainage problem and they were not needed, the drains were filled in.

In Houses 054, 069, and 076, an effort was made to isolate the crawl space from the basement by constructing wooden access doors that were tightly sealed with weatherstripping (or, in one house, with metal tape). No effort was made to cover the exposed soil in the crawl spaces of these houses.

8.3 PERFORMANCE

8.3.1 Passive Sub-Slab Depressurization

Table 11 summarizes the results from the eight houses in which passive SSD was tested. Detailed results were presented in Table 8. To facilitate the summary comparison, only the cool-weather results from Table 8 are shown in Table 11, although the percentage reductions in Table 11 also include the mild-weather reductions.

TABLE 11. PASSIVE SUB-SLAB DEPRESSURIZATION RESULTS

House	House Type	Test Stage	Story	Radon Level (pCi/L) Before	Radon Level (pCi/L) After	% Reduction
004	B	1	B	24.1-64.3	7 - 9.1	60 - 80
004	B	1	LA	25 -37.5	8 -13.1	0 - 70
008	B+SOG	1	B	8.3-64.9	3.0- 6.0	30 - 75
008	B+SOG	1	LA	3.8- 5.3	1.8- 3.5	30 - 60
032	B	1	B	11.5-11.9	5.7- 8.4	30 - 40
032	B	1	LA	6.4-10.9	4.7- 6.0	0 - 60
054	B+CS	1	B	12.4-23.2	13.5	0 - 40
054	B+CS	1	LA	--	--	--
069	B+CS	1	B	13.2-20.0	7.2	40 - 70
069	B+CS	1	LA	8.5-13.2	4.3	50 - 75
076	B+CS	1	B	9.5-16.8	2.8- 9.8	0 - 80
076	B+CS	1	LA	4.3- 4.7	0.9- 3.4	30 - 80
079	B	1	B	17.2-24.0	0.6- 2.6	70 - 90
079	B	1	LA	10.6	0.3- 2.0	80 - 90
106	B+SOG	1	B	19.2-58	10	0 - 50
106	B+SOG	1	LA	7.1-18	5	About 50

Note: B = basement; SOG = slab on grade; CS = crawl space
LA = living area.

The radon concentrations and the percentage reductions are shown as a range for each house, since the pre- and post-mitigation measurements were obtained using a variety of measurement techniques and were separated in time by a year or more in some cases. The broad ranges for some houses (e.g., 0 to 80% reduction for House 076) reflect the uncertainty in the understanding of passive system performance. The broad ranges probably result not only from natural variation in radon source term over the period between the pre- and post-mitigation measurements, but also from variations in the effectiveness of the systems between one post-mitigation measurement and another (due to differences in wind velocity or temperature, causing the passive suction to vary).

As shown in the table, the percentage reduction in radon levels with the passive SSD systems varied widely from house to house, ranging from 0% to 90%. Reductions were commonly moderate (30 to 70%). Only in House 079 did the passive system appear to give reductions consistently greater than 70% and reduce the house below 4 pCi/L both in the basement and upstairs.

House 079 may have experienced such good results because it was a textbook-case house for passive SSD: a) it was a pure basement house, without an adjoining wing; b) it had good sub-slab communication; and c) it had poured concrete foundation walls, thus minimizing wall-related entry routes. The one other house which also met all three of these criteria was House 004; this house, too, achieved high reductions in the basement (60-80%). Both Houses 004 and 079 had pits under the suction pipes (excavated as part of the SSD installation in House 004, by virtue of the unused sump pit in House 079). House 004 had the additional advantage of having two passive suction pipes instead of just one.

In all of the houses having poured concrete foundation walls (Houses 004, 008, 076, and 079), the upper end of the range of percentage reductions was 70% or greater. This was true regardless of whether or not there was an adjoining slab-on-grade or crawl-space wing. All four of these houses had reasonably good communication.

Among the houses with block walls (Houses 032, 054, 069, and 106), only one (069) achieved an upper-end reduction greater than 50%. House 069, which was observed to have several inches of sub-slab aggregate, achieved up to 70% reduction, despite the fact that it had an adjoining crawl space. (The crawl space had been isolated from the basement, and had additional foundation vents installed, during this study.) House 106 achieved no better than 50% reduction despite the fact that: a) it had 4 inches of aggregate; b) the top voids in the block wall were mortared shut when the house was built; and c) the floor/wall joint and an unused sump pit were carefully sealed as part of this effort. House 106 did have the complexity of an adjoining slab on grade. The only pure basement house with block walls (032) had several apparent disadvantages: the aggregate had been at least partially mixed with mud during house construction, to the extent that the material observed under the slab looked like hard-packed soil; and the top wall voids were open. Only 30-40% reduction was achieved in the basement. Perhaps the poorest reductions (0-40%) were achieved in House 054; in addition to the block foundation wall, this house was found to have poor (uneven) communication under the slab (to the extent that inadequate reductions were achieved even after the mitigation system was activated in a later stage). House 054 also had the complexity of an adjoining crawl space, which was isolated from the basement and provided with one additional foundation vent as part of this project.

Table 12 summarizes the pressure measurements in the passive SSD systems, including the suction in the passive stack, and the suction developed underneath the slab.

TABLE 12. SUCTIONS DEVELOPED BY PASSIVE SSD SYSTEMS

House	Stack Suction (in. WG)	Sub-Slab Suction (in. WG)	Weather Conditions
004	-0.008 to -0.023	--	30 °F, no wind
008	-0.01 to -0.10	-0.005 to -0.06 (1 ft from pipe)	65 °F, breezy
032	-0.008 to -0.048	-0.005 to -0.04 (2 ft from pipe) -0.001 to -0.002 (18 ft from pipe)	65 °F, slight breeze
054	-0.05 to -0.09	0.0 (at 5 ft) +0.007 (at 10 ft)	40 °F, breezy
069	-0.03 to -0.07	-0.017 (at 1.5 ft) +0.005 (at 15 ft)	65 °F, windy
076	-0.076[1] -0.008 to -0.050[2]	-0.007[2] to -0.035[1] (at 5 ft) -0.001[2] to -0.003[1] (at 28 ft)	65 °F
079	0.0 to -0.044	0.0 to -0.038 (12 ft) 0.0 to -0.020 (40 ft)	Mild, slightly breezy
106	-0.035	-0.010 (at 1.5 ft) -0.005 (at 22 ft)	55 °F, slight breeze
	-1.25 to -2.50[3]	--	45 °F, windy

[1] Furnace operating
[2] Furnace off
[3] Measurement is suspiciously high.

It should be noted that these suction measurements in Table 12 were not generally made at the same time that the radon measurements in Table 11 were conducted. Thus, while the suction measurements generally suggest the types of suctions that can be developed by the passive systems, they do not necessarily reflect the actual suctions/weather conditions that existed during the radon measurements.

As shown in the table, suctions in the passive stacks could typically be 0.05 to 0.10 in. WG during breezy weather, even when the temperature was relatively mild. With no breeze, the suctions could be below 0.01 in. WG. It would be anticipated that system performance might vary depending upon the temperature and winds; however, resources were not available in this project to continuously measure the radon-versus-stack-suction relationship.

In House 106, a suction of 1.25 to 2.50 in. WG in the passive stack was reported by the system installers on a windy, 45 °F March day immediately after installation was completed. If this measurement were valid, it would represent an extraordinarily high value for a passive system. Although the reading is suspiciously high, perhaps this suction could have been created by a combination of: strong winds; and heating of the unused chimney flue (that served as the stack) by hot combustion products in one or two of the neighboring flues. A later measurement at somewhat warmer and less windy conditions showed only 0.035 in. WG in the stack.

In House 076, where the furnace flue served as the stack, a suction of 0.076 in. WG was observed when the furnace was operating, falling to 0.008 - 0.050 in. WG when the furnace was off. While 0.076 in. WG is at the upper end of the range observed in all of the houses, it is not as high as some transient values observed in other houses having only PVC stacks with wind turbines (up to 0.09 - 0.10 in. WG in Houses 008 and 054).

In all houses where sub-slab test holes were drilled within a foot or two of the passive suction pipe, it was found that sub-slab depressurization was in fact being created by the system (0 to 0.06 in. WG). In houses where sub-slab measurements were made at points remote from the pipe (20 to 40 ft away), the sub-slab was being depressurized at those remote points in four of the houses (032, 076, 079, and 106). One of the best sub-slab depressurizations was observed in House 079 (0.038 in. WG at 12 ft, and 0.005 in. WG, or about 1 Pa, at 40 ft); as mentioned previously, House 079 gave the best radon reduction performance among the passive SSD houses. House 076 -- which, like 079, had poured concrete foundation walls -- had sub-slab suctions of 0.001 to 0.003 in. WG at 28 ft, and achieved a broad range of reductions extending as high as 80%. The other two houses which showed some limited depressurization at distance -- House 032 (0.001 to 0.002 in. WG at 18 ft) and 106 (0.005 at 22 ft) -- showed only moderate radon reductions. Perhaps this is because they had block foundations, and the wall was still a source; in addition, 106 had an adjoining slab on grade which was not being treated.

In two of the houses with sub-slab measurements at distance (Houses 054 and 069), the sub-slab was not being depressurized by the system during the measurements. With House 054, this result is not surprising, because the radon reductions were poor, and because subsequent measurements with an active system operating confirmed poor communication under some parts of the slab. But House 069 was the block-foundation house that appeared to be one of the more successful.

Again, it is emphasized that these suction measurements were usually conducted at times different from when the radon measurements were being made. Since he performance of the passive system can depend upon weather conditions, the suctions actually being experience during the time that radon was being measured might have been different from those reported in Table 12.

8.3.2 Active Sub-Slab Depressurization

Active sub-slab ventilation systems were installed in nine houses. In five of these houses, passive sub-slab ventilation systems had originally been tested, and were converted to active systems during a later stage; in the other four houses, no previous work had been performed. The radon reductions for each house are listed in Table 13. To facilitate this summary comparison, only the cool-weather radon measurements from Table 9 are summarized here.

TABLE 13. ACTIVE SUB-SLAB DEPRESSURIZATION RESULTS

House	House Type	Test Stage	Story	Radon Level (pCi/L) Before	Radon Level (pCi/L) After	% Reduction
004	B	2	B	11.7-64.3	0.4- 0.8	92 - 99
004	B	2	LA	6.7-37.5	0.2- 2.0	92 - 99
011	B+SOG	1	B	88.3-178	0.1- 1.9	96 - 99+
011	B+SOG	1	LA	43.1	0.5- 3.1	93 - 99
032	B	2	B	3.8-11.9	0.7- 1.4	82 - 90
032	B	2	LA	3.7-10.9	1.2- 1.3	65 - 89
041	B+SOG	2	B	22.7-298	0.4- 1.4	94 - 99+
041	B+SOG	2	LA	24.5-231.6	0.5- 1.2	95 - 99+
054	B+CS	2	B	12.4-33.4	5.7-16.0	50 - 90
054	B+CS	2	LA	--	--	Unknown
076	B+CS	2	B	8.9-16.8	0.5- 2.9	70 - 97
076	B+CS	2	LA	4.3- 4.7	0.6- 0.7	About 85
079	B	2	B	17.2-24.0	0.4- 0.9	95 - 98
079	B	2	LA	10.6	<0.1- 1.1	90 - 99
110	SOG	1	LA	23.8-31.0	0.6- 1.2	92 - 99
143	B	1	B	52.6-71	1.6- 3.5	93 - 97
143	B	1	LA	27.3-57.2	1.3- 2.8	92 - 95

As described in Section 8.2, the SSD systems in these houses consisted of: a) a single suction pipe through the basement slab, in Houses 032, 054, 076, 079 (an unused sump pit), and 143; b) two suction pipes (one at either end of the basement) in House 004; c) two pipes through the basement slab, and two horizontally through the stem wall underneath the adjoining slab on grade, in Houses 011 and 041; and three pipes horizontally through the foundation wall from outdoors in House 110. Because the three slabs in House 110 had been poured at different times as the house was enlarged, there were interior footings between the different pours, and each slab was thus treated with a separate SSD pipe. There were no other known obstructions under the slabs in this house; in particular, the house had hot water/baseboard heat, so that there were no forced-air ducts under the slabs. Nor were there forced-air ducts under the slab-on-grade wings of Houses 011 and 041. In all houses, the results shown in Table 13 are for the case where the SSD fans were operating at full power.

Eight of the nine houses have been reduced below 4 pCi/L, consistent with the effective radon reduction performance that has commonly been reported for active SSD systems. Five of the nine have been unambiguously reduced to 2 pCi/L or less both in the basement and in the living area upstairs. The radon reductions range above 90% in all of the houses but two. And one of those two (House 032) was reduced below 2 pCi/L; the percentage reduction is less than 90% because the pre-mitigation radon concentrations were only moderately elevated.

House 054 is the only one of the nine which was not reduced below 4 pCi/L. The percentage reduction in this house could be as low as 50%. This is also the house which was least successful with a passive SSD system, as discussed in Section 8.3.1. The primary reason for the poorer performance in this house is uneven, sometimes poor communication under the basement slab of this basement-plus-crawl-space house. Suction field extension measurements showed that system suction was not extending under all portions of the slab. Added complexities included the block foundation walls, and the fact that there is an adjoining crawl space.

Except for House 054, the other houses were generally found to have fairly good communication, and the suction field appeared to extend beneath most of the slab. This is shown in Table 14.

TABLE 14. SUCTIONS DEVELOPED BY ACTIVE SSD SYSTEMS

House	Stack Suction (in. WG)	Sub-Slab Suction (in. WG)
004	-1.5	-0.84 (10 ft from east pipe) -0.75 (22 ft from either pipe)
011	-0.05 to -0.11	-0.015 to -0.022 (bsmt slab, 20 ft from either bsmt pipe)
032	-1.4	-0.41 (2 ft from suction pipe) -0.16 (28 ft from pipe)
041	-0.14 to -0.24	-0.07 (bmst slab, 18 ft away) -0.01 (SOG slab, 22 ft away)
054	N/A	N/A[1]
076	-1.6	-0.83 (5 ft from suction pipe) -0.09 (28 ft from pipe)
079	-1.3	-0.91 (12 ft from suction point) -0.88 (40 ft from point)
110	-1.3 to -1.4	-0.004 (~20 ft away, on Slab 1) -0.002 (~25 ft away, on Slab 2) -0.014 (~5 ft away, on Slab 3)
143	-1.2	-1.1 (5 ft away, east slab) -0.02 (21 ft away, east slab) 0 (5 ft away, west slab)

[1] N/A = not available. Subsequent measurements showed that suction did not extend under all parts of slab.

In general, over an inch of water suction was created in the suction pipes by the fan, except in Houses 011 and 041, where air leakage into the system from the legs through the stem wall under the adjoining slab on grade reduced the suction to 0.05 to 0.24 in.

WG. With the exception of Houses 054 and 143, at least 0.015 in. WG suction was being maintained under basement slabs by the system at points 20 to 40 feet from the suction pipes; commonly, the suctions under the basement slabs were at least 0.1 in. WG. Even House 032, where the aggregate was thought to be filled with mud, good depressurization (0.16 in. WG) was observed 28 ft from the single, centrally-located suction pipe. Under slabs on grade (House 110, and wings of Houses 011 and 041), the suction was 0.002 to 0.01 in. WG at remote points. From the results in Table 13, this suction under the slabs on grade was apparently sufficiently large and sufficiently consistent to provide radon reductions typically to below 2 pCi/L in those three houses. The suction under the slabs on grade might be being reduced by outdoor air leakage into the system through the good aggregate layer known to underlie these slabs.

House 143 was known to not have aggregate under the slab, and this house had very uneven communication, as did 054. In 143, suction extended well under the eastern side of the basement slab, but did not extend at measurable levels under the other side. However, the one-pipe system in 143 was able nevertheless to achieve over 90% reduction, to levels below 4 pCi/L, while the residual levels in 054 were 5.7 to 16 pCi/L. Perhaps the poorer results in House 054 occurred because: a) it had hollow-block foundation walls (143 also had block walls, but they were filled with concrete); and b) it had the complexity of an adjoining crawl space (143 was a pure basement).

From the reasonably good results obtained in House 143 (with no aggregate) and in House 032 (where there was mud in the aggregate), it appears that SSD systems can be forgiving in some cases. Visual observation of poor aggregate, by itself, is not necessarily proof that sub-slab suction field extension will be poor.

Where communication is good, it does not appear that the material of construction of the foundation wall is critical in influencing the performance of an active SSD system, to the extent it might have been for the passive systems. The two pure basements with poured walls (Houses 004 and 079) perhaps achieved somewhat better radon reductions (92-99%) than did the one pure basement with block walls that had reasonable communication (House 032, which achieved 82-90% reduction). This comparison is complicated by the fact that the initial radon levels in 032 were lower; the residual radon levels in 032 were reduced to the same value (< 2 pCi/L) as the other two, and achieved these levels despite the presence of mud in the aggregate. Among the two houses with basements and adjoining slabs on grade, the one with a block foundation wall (House 011) did only marginally poorer than did the one with a poured foundation (House 041).

Thus, it would appear that having reasonable communication is more important than the material of the foundation wall. Wall-related entry routes in block walls -- even open top voids, as in House 032 -- can apparently be treated reasonably well by an active SSD system, if the suction can extend well under the slab.

Based upon the success of the SSD installation in House 076, it would appear that -- in basement houses having an adjoining crawl space -- the house might be effectively mitigated via SSD in the basement alone, without having to apply sub-liner depressurization to the crawl space, _if_ the communication under the basement slab is good. In this house, pre-mitigation levels of 8.9 to 16.8 pCi/L in the basement were reduced to 0.5 to 2.9 pCi/L. (In 076, there was some isolation of the crawl space from the basement, and addition of a second foundation vent in the crawl space, as part of this project; otherwise, the crawl space was untreated.) In House 054 -- a basement-plus-crawl-space house where the communication was _not_ good -- the basement SSD system was not even able to treat the entire basement. A more effective basement SSD system would have to be tested in this house before the possible need to also treat the crawl space could be assessed.

In several of the houses, tests were conducted to assess how system suction and sub-slab suction field extension varied as the fan power was reduced. However, no definitive tests were conducted to assess the effect of reduced fan power on indoor radon levels.

8.4 COSTS

The installation costs of the passive sub-slab depressurization systems ranged from $1,190 to $2,700, and averaged $1,900. The active sub-slab depressurization system installation costs ranged from $1,265 to $3,330, and averaged $2,070. The range in installation costs reflects the variability in conditions of each house, such as the need for multiple sub-slab suction holes or extensive entry route sealing. Most of the installation costs were associated with labor, and the remaining costs were associated with materials and supplies.

The average cost of converting the five passive sub-slab depressurization systems to active sub-slab depressurization systems was $610. A list of installation costs is presented in Appendix A.

The high labor costs were due, in part, to the fact that the systems were installed as part of a research and development project. The systems were installed in various phases involving a certain amount of inspection, testing, evaluation, and assessment. Actual commercial installation costs, therefore, would be lower than reported here.

CHAPTER 9

DRAIN TILE DEPRESSURIZATION

9.1 INTRODUCTION

Drain tiles are often placed around the perimeter of the foundation during house construction, to collect water and drain it away from the foundation. Drain tiles commonly consist of rigid 4-inch diameter perforated PVC pipes, or flexible piping. Tiles can be located around the interior of the foundation walls (under the slab), or along the exterior of the foundation. They might drain to a sump inside the house, or to an above-grade discharge or dry well outside the house. In some instances, the drain tile forms a complete loop. In other cases, it extends around only part of the foundation.

Producing suction, either passively or actively, on perimeter drain tiles can be an effective mitigation technique. Drain tiles are ideally located to extend the suction field around the perimeter, beside the wall/floor joint and the base of block foundation walls (potentially major soil gas entry routes). A typical drain tile depressurization (DTD) system is illustrated in Figure 2, for the case where interior drain tiles drain to a sump (the situation tested in this study). If sub-slab permeability is reasonably good, the suction might be expected to extend underneath the entire slab, treating all of the slab-related entry routes, especially with interior drain tiles. Also, the exterior surfaces of foundation walls may be accessed with exterior tiles, and also with interior tiles if the permeability of the soil below the foundation footers and adjacent to the foundation walls is sufficient.

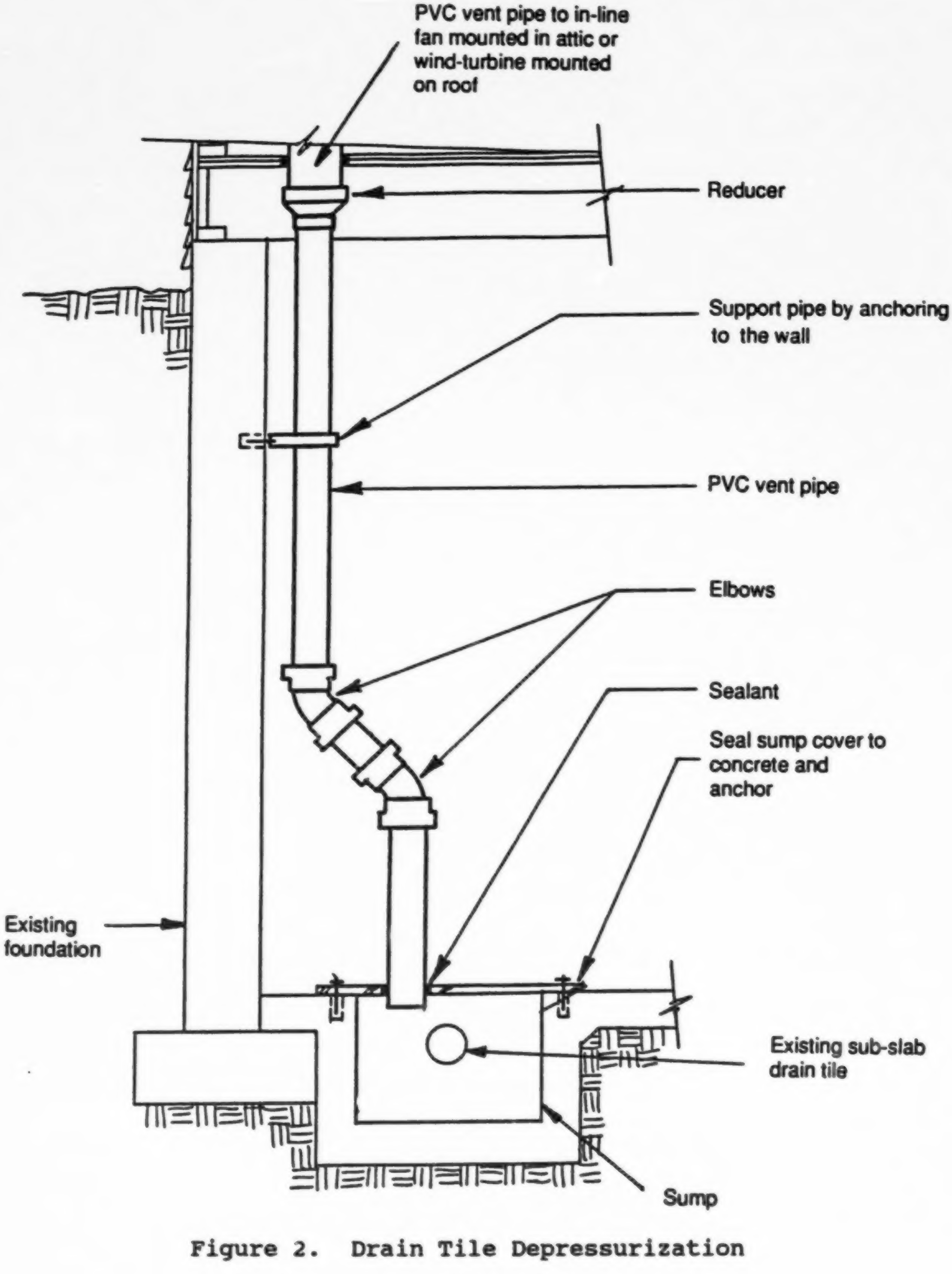

PVC vent pipe to in-line fan mounted in attic or wind-turbine mounted on roof
Reducer
Support pipe by anchoring to the wall
PVC vent pipe
Elbows
Sealant
Seal sump cover to concrete and anchor
Existing foundation
Existing sub-slab drain tile
Sump

Figure 2. Drain Tile Depressurization

Drain tile depressurization using passive measures to create suction was tested in House 061. Active DTD systems, using fans to produce suction, were installed in Houses 010 and 061. The active DTD system in House 010 was installed during Stage 3, after the Stage 1 and 2 sealing efforts described in Section 7 proved unsuccessful. The Stage 1 passive system in House 061 was converted to an active system in Stage 2, due to insufficient radon reductions by the passive system.

Both houses were pure basement houses, with no adjoining slab-on-grade or crawl-space wing; both had block foundation walls. Both houses had sumps connected to the drain tiles. The tiles in House 010 were reported by the owner to form a complete loop around the basement perimeter, inside the footings. The extent of the tiles under House 061, and whether they were inside or outside the footings, is not known. Good aggregate was seen under both slabs. House 010 had cap blocks as the top course of the foundation wall; House 061 had open top voids, which were inaccessible due to the sill plate.

9.2 INSTALLATION TECHNIQUES

For the Stage 1 passive DTD system, a circular plywood cover was attached with screws over the sump, fit into a recessed lip in the slab around the sump perimeter. The gap between this cover and the outside circumference of the lip was sealed with flowable urethane caulk. The sump was not necessary for water drainage; the owner had removed the sump pump, and nothing drained into the sump from inside the basement. Thus, the only penetration through the sump cover was the 4-in. diameter PVC suction pipe. This pipe extended straight up through the false ceiling in the basement, then ran horizontally above the ceiling to a point where it could run up through the living area into the attic. In the attic, it became a 6-inch pipe, which went through the roof and was connected to a

12-inch diameter wind turbine. Because the basement was almost completely finished, inspection of the slab and walls for cracks was not possible, and little entry route sealing could be done. The sealing was limited to closing a hole through the slab in the utility room.

In Stage 2, this passive system in House 061 was converted to an active system by installing a 270 cfm in-line duct fan on the pipe in the attic.

The basement of House 010 had been subjected to an intensive sealing effort before the active DTD system was installed. The only remaining apparent entry route was the porous surface of the block wall, which had not been sufficiently sealed by the waterproofing paint that had been applied in Stage 2 (see Section 7). A hole was cut through the plastic sump cover that had been installed during Stage 1, and a 4-inch PVC suction pipe was inserted. The 4-inch pipe was sealed to the plastic sump cover with polyurethane. The pipe was routed out of the house through the band joist, because there was no reasonable way for taking the pipe up through the house. The system exhausted at grade level, because the owner did not want the pipe going up to the eaves outside the house. A 270 cfm in-line duct fan was mounted on the pipe inside the basement, because the owner did not want it outdoors.

9.3 PERFORMANCE

9.3.1 Passive Drain Tile Depressurization

The radon reduction results from the passive DTD testing in House 061 are summarized in Table 15. More detailed radon data were presented in Table 8. Only the cool-weather data from Table 8 are included in Table 15, although the percentage reduction figures include the performance during milder weather.

TABLE 15. PASSIVE DRAIN TILE DEPRESSURIZATION RESULTS

House	House Type	Test Stage	Story	Radon Level (pCi/L) Before	After	% Reduction
061	B	1	B	9.1-14.5	7.0	20 - 50
061	B	1	LA	7.7	6.5	About 15

As shown, the radon reductions achieved by this system were moderate, at best. The house was still above 4 pCi/L during cold weather, both in the basement and upstairs.

The passive depressurization system generated a suction of 0.020 in. WG in the passive stack under slightly breezy conditions, with an outdoor temperature of 65 °F. The flow in the stack was too low to measure using the electronic anemometer, but was estimated from tracer gas tests to be only about 0.3 cfm. Suction under the basement slab (at a point about 25 ft from the sump, and about 5 ft from the nearest foundation wall) fluctuated from being under slight suction to being under pressure, and was dependent on wind speeds. Therefore, the passive ventilation system was influencing the sub-slab area to a degree. During more windy and colder conditions, the passive ventilation system might have produced greater suction.

Due to the heavy finish in the basement, it did not appear feasible to attempt to improve the performance of this passive system by sealing additional slab and wall cracks/openings. Thus, this system was converted to an active system in Stage 2.

9.3.2 Active Drain Tile Depressurization

The radon reduction results from the two active DTD systems are summarized in Table 16.

TABLE 16. ACTIVE DRAIN TILE DEPRESSURIZATION RESULTS

House	House Type	Test Stage	Story	Radon Level (pCi/L) Before	Radon Level (pCi/L) After	% Reduction
010	B	3	B	6.8-17.6	0.3	Over 95
010	B	3	LA	2.3-11.8	0.2	Over 90
061	B	2	B	5.9-14.5	0.4	Over 90
061	B	2	LA	5.2- 7.7	0.4	Over 90

Significant reductions were achieved in both houses. Unfortunately, the post-mitigation measurement in both houses consists of only a single two-day Pylon measurement in January 1989. These final installations were completed too late to permit a 3-month cold-weather alpha-track measurement after the active DTD systems were installed. (Alpha-track detectors were in place when the active systems were installed; thus, the period covered by these detectors overlaps both the active system and the previous passive system in both houses.) Because of the limited post-mitigation data, the system performance shown in Table 16 has an increased level of uncertainty.

The good performance in House 061 indicates that active DTD can be very effective even when essentially none of the slab- and wall-related openings are sealed, if there is reasonably good communication under the slab. The drain tile loop in this house might not even be complete.

Table 17 presents the suction produced below the slabs by these active systems. In House 010, the suction extended well. In the corner of the basement diagonally opposite the sump, the suction was half of what it was near the sump; this is consistent with the report that a complete loop of interior drain tiles existed. In the center of the slab in House 010, away from the foundation walls, the suction was also good, confirming the observation that a good layer of aggregate existed. However, in House 061, sub-slab depressurizations were relatively limited (but clearly measurable)

TABLE 17. SUCTIONS DEVELOPED BY ACTIVE DTD

House	Stack Suction (in. WG)	Sub-Slab Suction (in. WG)
010	-0.51	-0.22 (5 ft from sump) -0.13 (center of slab) -0.11 (opposite corner)
061	-0.90	-0.048 (1 ft from sump) -0.024 (10 ft from sump, 5 ft from foundation wall) -0.004 to 0.012 (25 ft from sump, 5 ft from wall)

even near the sump, dropping to as low as 0.004 in. WG near the rear wall, half-way across the basement from the sump (which is also near the rear wall). This relatively low depressurization is developed, despite good suction in the exhaust stack, suggesting that the drain tile loop is in fact not complete. The results also suggest that communication underneath the slab might not be good in this house; in House 079, where no drain tiles connected to the sump, much better sub-slab depressurizations were achieved (see Section 8.3.2).

9.4 COSTS

The cost of sealing entry routes and installing an active drain tile depressurization system in House 010 was $2,290. In House 061, the installation cost for the passive depressurization system was $2,145. Converting the passive system to an active system in House 061 required an additional $460.

CHAPTER 10

SUB-LINER DEPRESSURIZATION IN CRAWL SPACES

10.1 INTRODUCTION

Unpaved crawl spaces provide a large area of exposed earth immediately below the living area of the house. Radon from the crawl-space soil can move into the house through openings in the sub-flooring. In addition, if the crawl space adjoins a basement wing, radon can move from the crawl space into the basement if the crawl space is not sufficiently well isolated.

In some cases, increased ventilation of the crawl space does not provide sufficient radon reductions, and/or creates an unacceptable heating/cooling penalty in the living area. In these cases, a variation of active soil depressurization, referred to here as sub-liner depressurization (SLD), has been found by some investigators to be very effective in reducing radon levels. This technique, illustrated in Figure 3, involves placing a liner of some suitable material (commonly polyethylene sheeting) over some portion, or all, of the crawl-space soil, effectively creating a plastic "slab". The area between the liner and the soil is then depressurized, analogous to sub-slab depressurization.

Further testing is needed to fully understand, and to optimize the design and performance of, the SLD technique. One issue is the extent to which the liner must be sealed to the perimeter foundation wall, and to which the crawl-space floor needs to be covered, in order for the system to be effective under various conditions. Providing complete coverage, and careful perimeter sealing, can be difficult and time-consuming (and thus expensive), especially when

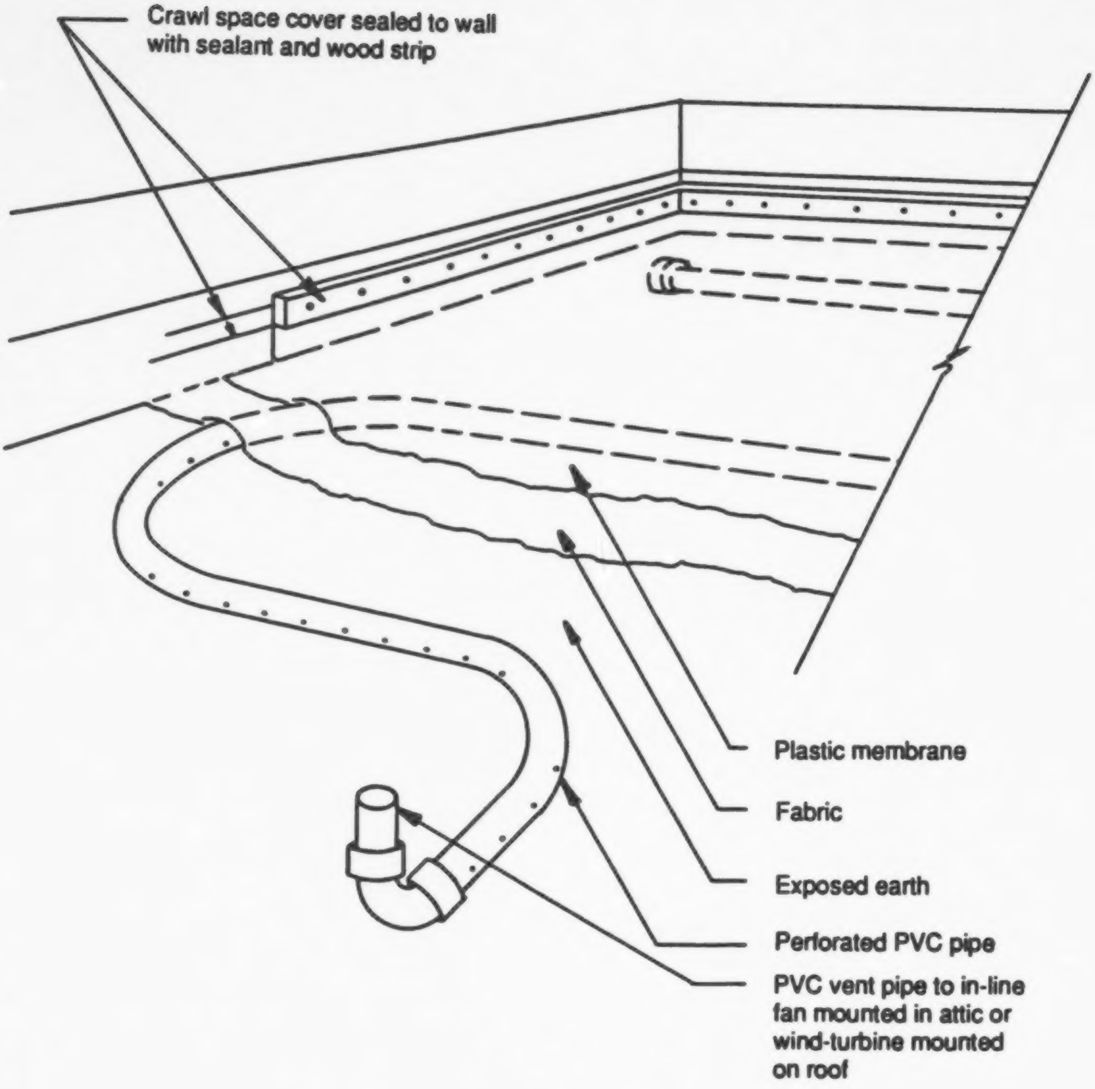

Crawl space cover sealed to wall with sealant and wood strip
Plastic membrane
Fabric
Exposed earth
Perforated PVC pipe
PVC vent pipe to in-line fan mounted in attic or wind-turbine mounted on roof

Figure 3. Sub-Liner Depressurization in a Crawl Space

there is inadequate head room in the crawl space, and when the crawl space contains obstructions such as furnaces. Another issue is how to best ensure that the suction field extends underneath the liner under different circumstances. One approach is to place perforated piping under the liner, as shown in the figure.

In this project, passive SLD was tested in one house, House 047. The objective was to determine whether -- by completely covering the crawl-space soil, and by carefully sealing the liner to the foundation wall around the perimeter -- a passive SLD system could be made to work. House 047 was a textbook case for this approach in the sense that the crawl space was relatively small (about 12 by 24 ft), had reasonably good head room, and was free of obstructions. Also, the foundation walls were poured concrete, avoiding any loss of depressurization due to air leakage into the sub-liner area through the walls. Radon measurements in the crawl space confirmed that it was an important source; while basement radon concentrations averaged 6.5 pCi/L over one two-day period, crawl-space levels averaged 28.5 pCi/L. However, the house was not fully ideal, since there was a basement wing adjoining the crawl space, thus complicating data interpretation. In this testing, the unfinished basement was treated solely by sealing entry routes. Since the foundation walls were poured concrete, and since the crawl space appeared to be the major source, it was thought that this approach might be sufficient for the basement in this case.

10.2 INSTALLATION TECHNIQUES

To distribute the suction under the liner, a single straight length of rigid perforated 4-in. PVC pipe was laid parallel to the long dimension of the crawl space. Since the crawl space was only 12 ft wide, no part of the crawl space floor was more than 6 ft from the pipe. This pipe was capped at one end (the end nearest the crawl-space entry door). The other end was connected, via a short length of sheet metal pipe, to the central furnace flue at the far end of the crawl space. The flue was utilized as the passive stack, in an effort to develop some extra suction by means of the hot combustion products rising up the flue.

A fabric mat was then laid over the crawl-space floor, covering the pipe, to provide some support for the plastic liner and reduce the risk of it being ruptured by persons moving about in the crawl space. The liner was placed on top of the fabric. The liner was Super Sampson 400, a cross-laminated high-density polyethylene polymer which was puncture-resistant and had a high tensile strength. Sheets of this material were 4 mil, but had a strength equivalent to 10-mil-thick standard polyethylene sheeting. The liner was laid as a single sheet, with no seams, cut to the dimensions of the small crawl space. This sheet was attached to the perimeter wall using a furring strip, with a continuous bead of caulk applied at the seam between the furring strip and the wall.

The crawl space was not well isolated from the basement. There is a frame wall, on top of a stem wall, between the basement and the crawl space. However, the access door between the basement and the crawl space is not well fitted, and there are large openings in the frame wall around the flue from the furnace in the basement; the flue duct penetrates this wall, and runs the length of the crawl space. Given the condition of the basement/crawl interface, it was not practical to effectively isolate the crawl as part of this project.

Significant entry routes in the basement were sealed. A plastic cover was sealed over the sump; since the pedestal pump was left in the sump, the cover had the appearance of an inverted trash can, to fit over the pump. The cover was attached to the slab with an annular section of plywood, with caulk around the seams. A "floor" drain (in a concrete pad outside the basement door) drained into the sump; a trap for this drain was created inside the sump, in the event that it became necessary to depressurize the sump in a later stage. In effect, the sump was being passively vented to the outdoors via the sump pump discharge pipe, which came up through the sump cover and penetrated the basement wall. Some interior slab cracks were routed and sealed with flowable urethane caulk. The wall/floor joint was also supposed to be routed and sealed. Sealing was also carried out around some wall penetrations.

Sub-liner depressurization was also tested in conjunction with sub-slab depressurization in two other houses (Houses 074 and 163). This testing of combined mitigation approaches is addressed in Chapter 11.

While use of the furnace flue provides the advantages of a ready-made stack and potentially increased passive suction, there are several concerns. One major concern is that the SLD system might impact the natural draft in the flue, potentially permitting carbon monoxide to enter the basement. A number of CO measurements in the basement under various conditions demonstrated that the CO level was always below the detection limit of the Draeger tube (<3 ppm); by comparison, the OSHA limit is 50 ppm. Another potential concern is that the moisture present in the soil gas might condense in the flue under some conditions, accelerating rusting of the flue, again impacting the draft which keeps combustion products out of the living area. The metal flue requires periodic inspections to ensure that its integrity is maintained.

10.3 PERFORMANCE

The performance of the passive sub-liner depressurization system in House 047 is summarized in Table 18. The measurements shown here include only the cool-weather data from Table 8, to simplify comparison.

TABLE 18. PASSIVE SUB-LINER DEPRESSURIZATION RESULTS

House	House Type[1]	Test Stage	Story	Radon Level (pCi/L) Before	After	% Reduction
047	B+CS	1	B	6.5-11.1	2.4- 3.2	20 - 70
047	B+CS	1	CS	28.5	1.0- 2.8	90 - 96

[1] B = basement; CS = crawl space

As shown, a moderate level of radon reduction was achieved in the basement, through the combination of sealing the basement entry routes and reducing the amount of radon flowing into the basement from the crawl space. This moderate reduction was sufficient to reduce basement concentrations to below 4 pCi/L, since the levels were only slightly elevated to begin with. The concentrations in the crawl space were reduced by an even greater amount (apparently 90% or more). It is noted that the values in Table 18 were all obtained during cool weather, when both the driving force for soil gas entry, and the passive suction in the stack, would be expected to be the greatest. House 047 was the only one of the 19 houses tested in this project to retain a passive system at the conclusion of the testing.

With the aid of the furnace flue, the passive SLD system was able to generate a significant flow in the suction pipe, relative to the other passive systems that were tested in this project. The flow rate was measured on a day when the outside temperature was 35 °F, and when it was windy. With the furnace operating, the vent pipe flow rate ranged from 13 to 23 cubic feet per minute (cfm). With the furnace off (but the flue still warm), the flow rate ranged from 9 to 26 cfm, produced by the thermal stack effect and the wind flowing over the roof-line. Flow rate measurements were not taken during warm weather and calm conditions. Long-term (3 months) post-mitigation radon levels were measured during warm weather and were 1.8 pCi/L in the crawl space and 1.3 pCi/L in the basement, indicating that the performance of the passive depressurization system did not degrade during warm weather, when the furnace would not be operating.

10.4 COSTS

The cost to install the passive SLD system and to perform entry routes sealing at House 047 was $1,300.

CHAPTER 11

COMBINED SOIL DEPRESSURIZATION SYSTEMS

11.1 INTRODUCTION

In some cases, it is necessary to install a combination of soil depressurization systems in a house in order to treat different entry routes that cannot be treated by a single depressurization approach. For instance, in a house with a basement slab and hollow block basement walls, a sub-slab depressurization system may be able to depressurize the entry routes associated with the slab and floor/wall joints. However, in some cases, this system may not be capable of treating the block wall entry routes, possibly due to poor communication between the slab and the block walls, or due to low suction generated by the ventilation system. For this situation, a block wall depressurization system might also be needed to draw radon gas away from wall-related entry routes, especially if the walls are a major contributor to the infiltration of radon into the basement. Another example would be a basement with an adjoining crawl space where both wings are an important radon source; in this case, it may be necessary to combine sub-slab and sub-liner depressurization.

The combinations of soil depressurization systems tested in this project were:

1) sub-slab plus drain tile depressurization,
2) sub-slab plus sub-liner depressurization, and
3) sub-slab plus block wall depressurization.

Both passive and active techniques were tested for each combination of depressurization systems. The specific systems tested are summarized in Table 19 below.

TABLE 19. SOIL DEPRESSURIZATION COMBINATIONS TESTED

House	House Type	Test Phase	Passive or Active	Combination Tested
008	B+SOG	2	Active	SSD + DTD
069	B+CS	2	Passive	SSD + BWD
069	B+CS	3	Active	SSD + BWD
074	B+CS	1	Passive	SSD + SLD
074	B+CS	2	Active	SSD + SLD
096	B+SOG	1	Passive	SSD + DTD
096	B+SOG	2	Active	SSD + DTD
106	B+SOG	2	Passive	SSD + BWD
106	B+SOG	3	Active	SSD + BWD
126	B(+CS)	1	Active	SSD + DTD
163	B+CS	1	Active	SSD + SLD

In four of these houses, the combined mitigation system was first tested passively, then converted to an active system in the next stage. In Houses 126 and 163, active systems were installed immediately in Stage 1. In House 008, a passive SSD system in Stage 1 was converted to an active SSD plus DTD system in Stage 2, by tying an existing sump into the active system.

In some of these cases, the combined system is necessitated by the fact that the house has a combined substructure (B+SOG or B+CS), and both wings require treatment. In other cases, the combined mitigation system was installed during passive testing, because the passive system in one wing was unable to treat both wings; when the system was subsequently activated by adding a fan, the combined system was left otherwise as was. It is possible that, had the active system been installed in the first stage, it might have been possible to treat the entire house just with active treatment of the basement wing, in some of these cases.

11.2 INSTALLATION TECHNIQUES

In House 008, a basement house with an adjoining slab on grade, the Stage 1 system had involved passive SSD with a single suction pipe inserted through the basement slab near a foundation wall, on the opposite side of the basement from the sump and from the stem wall connecting to the adjoining slab on grade. This location for the SSD pipe had been chosen in an effort to treat the floor/wall joint, and to tap into the expected backfill area near the footings, where permeability might most likely be reasonably good. A cover had been sealed over the sump as part of this earlier stage. A single drain tile emptied into the sump; the owner reported that there was a complete drain tile loop around the basement wing, but it was not clear whether the tiles were inside or outside the footings. The Stage 1 installation has been described in Section 8. Only moderate radon reductions were achieved by this passive system, with the basement still above 4 pCi/L. Thus, in Stage 2, a 270 cfm in-line duct fan was installed on the existing passive SSD stack in the attic. Also, in an effort to ensure greater reductions, a 4-in. PVC pipe was installed through the sump cover, and tapped into the 6-in. SSD pipe, creating a SSD + DTD system in the basement. With the drain tiles in the sump, there is an increased likelihood that the entire basement perimeter will be treated; in addition, since the sump is near the stem wall, there is an increased likelihood that the adjoining slab on grade might also be treated. No check valve was installed on the sump pump water discharge line, so some flow of outdoor air into the depressurized sump might have been occurring.

In House 069, the Stage 1 system -- involving passive SSD in the basement and increased natural ventilation of the crawl space -- had not reduced levels in either the basement or the living area below 4 pCi/L. Diagnostics showed that the passive suction was not extending underneath the entire basement slab (see Table 12), and that radon levels in the block stem wall between the basement and crawl space averaged 41.6 pCi/L over two days, indicating the wall was still a source. Accordingly, in Stage 2, a second 4-in. SSD pipe was inserted through the basement slab, near the adjoining crawl space, and a 4-in. pipe was inserted into block wall cavities in the wall between the basement and the crawl space. Both pipes were tapped into the existing 6-in. passive stack up through the house. When this improved passive system also failed to reduce cold-weather radon levels below 4 pCi/L on either story, the entire system was activated in Stage 3 by installing a 270 cfm in-line duct fan on the stack in the attic.

House 074 had a basement with an adjoining walk-in "crawl space". In fact, the interface between the basement and the crawl space was such that the crawl might be more accurately described as an unpaved section of the basement. A single SSD pipe was installed through the basement slab, about 4 ft from the crawl space. Because no aggregate was found under the slab, a 2 x 2 ft hole was jackhammered in the slab, and 8 ft^3 of material were removed and replaced with aggregate under the SSD pipe in an effort to improve suction field extension. This 4-in. SSD pipe was connected to the 8-in. metal flue for a wood stove located near the suction point, to utilize the flue as a ready-made passive stack, and to take advantage of the additional suction that would be created by the rising combustion products when the stove is operating. A complete loop of perforated 4-in. PVC pipe was laid around the perimeter inside the crawl space. The crawl-space floor was then covered with heavy-duty, 20-mil plastic sheeting, which was bonded to the perimeter walls, and sealed at seams between sheets. The 4-in. piping in the crawl space was connected to a 6-in. diameter passive stack that was located outside the house for the owner's convenience. With this exterior passive stack, of course, much of the natural thermally induced suction would be lost, although the suction created by wind effects should still be achieved. The perimeter expansion joint in the basement was removed, and sealed with flowable urethane caulk.

When this Stage 1 passive system in House 074 was not successful, the SSD and SLD legs were tapped together into the exterior 6-in. stack, and a 270 cfm in-line fan mounted on the top of the stack, exhausting above the eaves. The stack and fan were enclosed in a chase, for appearance.

House 096 had a basement and an adjoining slab on grade; during the course of this project, a crawl-space wing was added. The Stage 1 mitigation system included passive DTD via a sump in the basement, and passive SSD under the adjoining slab on grade. There are two drain tiles emptying into the sump, but it is not known whether they form a complete loop, or whether they are inside or outside the footings. A plastic cover was sealed over the sump, and a trap was provided in the sump for an exterior floor drain and the air conditioner condensate drain which emptied into the sump. A 4-in. suction pipe was installed through the sump cover, and run horizontally across the ceiling to an existing flue chase. This pipe connected to a 6-in. stack that was taken up through the chase, and ended with a wind turbine on the roof. Two 3-in. PVC pipes were inserted horizontally through the stem wall from inside the basement, to depressurize the adjoining slab on grade. These two pipes were connected to the flue from the central furnace, which was beside the stem wall, to make use of the flue as an enhanced passive stack.

When the Stage 1 passive system in House 096 did not achieve sufficient radon reductions, the horizontal pipes through the stem wall were disconnected from the furnace flue and tied into the 6-in. stack. A 270 cfm in-line duct fan was installed on this stack in the attic.

In House 106, a basement house with an adjoining slab on grade, the Stage 1 passive SSD system in the basement did not provide sufficient reductions (see Section 8). Diagnostic tests showed that radon concentrations inside the capped block foundation wall between the basement and the adjoining slab averaged 181 pCi/L over four days, indicating that the wall could still be an important source. Accordingly, in Stage 2, two 4-in. PVC pipes were installed horizontally into the block cavities in this wall, and were connected to the existing 6-in. SSD pipe (which in turn connected to the unused chimney flue that served as the passive stack).

When this passive SSD + BWD system in House 106 proved insufficient to reduce concentrations on either story below 4 pCi/L, the system was activated during Stage 3. A PVC exhaust pipe was inserted down through the unused flue from the roof and connected to the 6-in. SSD/BWD pipe. A 270 cfm in-line duct fan was installed in the 6-in. pipe inside the basement, since the owner did not want the stack to come up through the house, or the fan to be mounted on top of the chimney.

House 126 had been a basement house with an adjoining crawl space, having block foundation walls, at the time that house selection visits had been made in June 1987. However, prior to mitigation efforts, the homeowner excavated the crawl space and converted it to an extension of the basement, the extension having poured concrete walls. Under the slab of the extension, the owner had installed a complete loop of perforated drain tile, at EPA's suggestion. The owner had also decided to install an additional leg connecting to this drain tile loop, which came up through the slab and ran beside the walls above the slab; his intent was to create a "plenum wall" by enclosing this section of tile behind the framed stud wall built to conceal the concrete wall. This length of tile was between the concrete wall and plastic sheeting, which was attached to the new foundation wall at the bottom and top.

An active SSD + DTD system was installed in this house during Stage 1. In the original basement, a 4-in. PVC pipe was installed through the slab. The piping was directed out through the basement wall, where it connected to a 6-in. stack that rose above the eaves, with a 270 cfm in-line duct fan on top. The drain tile loop in the new basement extension was connected to a separate PVC pipe that also rose above the eaves, with a second 270 cfm fan on top.

House 163, a basement house with an adjoining crawl space, was known to have no aggregate under the slab, according to the owner who built the house. Thus, no passive testing appeared warranted, and the Stage 1 installation was an active SSD + SLD system. The SSD element consisted of a single 4-in. PVC pipe was installed through the slab near one end of the basement, remote from the crawl space. In view of the expected poor communication, a 2 x 2 ft hole was jackhammered in the slab, and 8 ft^3 of hard-packed soil was removed and replaced with aggregate under the suction pipe. In the crawl space, flexible perforated piping was laid in a serpentine pattern on the crawl-space floor. A 20-mil polyethylene membrane was laid over the floor in this unobstructed crawl space; the membrane was sealed to the perimeter walls with a caulked furring strip, and was sealed at seams between sheets of the membrane. The SSD and SLD systems were tied into a single PVC pipe which connected to a 270 cfm in-line duct fan mounted in the basement. The exhaust pipe from the fan went outdoors through the basement band joist, then ran up outside the house, exhausting above the eave.

11.3 PERFORMANCE

11.3.1 Sub-Slab Plus Drain Tile Depressurization

The performance of the passive SSD + DTD system in House 096 is summarized in Table 20. The performance of the active systems is summarized in Table 21. More detailed radon data for the passive and active systems were presented in Tables 8 and 9, respectively.

TABLE 20. PASSIVE SUB-SLAB + DRAIN TILE DEPRESSURIZATION RESULTS

House	House Type	Test Stage	Story	Radon Level (pCi/L) Before	Radon Level (pCi/L) After	% Reduction
096	B+SOG	1	B	16.2-23.0	4.4- 8.6	35 - 75
096	B+SOG	1	LA	4.3-15.7	1.0- 4.8	25 - 90

TABLE 21. ACTIVE SUB-SLAB + DRAIN TILE DEPRESSURIZATION RESULTS

House	House Type	Test Stage	Story	Radon Level (pCi/L) Before	Radon Level (pCi/L) After	% Reduction
008	B+SOG	2	B	8.3-64.9	0.2- 1.2	85 - 99
008	B+SOG	2	LA	3.8- 5.3	0.1- 0.5	87 - 98
096	B+SOG	2	B	7.0-23.0	0.5- 0.7	90 - 98
096	B+SOG	2	LA	2.2-15.7	<0.3- 0.5	80 - 99
126	B(+CS)	1	B	44.7-55.8	1.4- 1.9	96 - 98
126	B(+CS)	1	LA	No data	No data	Unknown

Consistent with the previously-presented data for passive systems, the passive SSD + DTD system in House 096 gave generally moderate reductions, insufficient to reduce either the basement or the living area consistently below 4 pCi/L. It is noted that -- despite the effort in House 096 to passively treat both the basement and the adjoining slab -- the radon reduction performance in this block-foundation house is in the same range as that achieved by passive systems in other combined-substructure houses shown in Table 11, where no effort was made to treat the wing adjoining the basement.

In all cases, the active SSD + DTD systems reduced the houses below 2 pCi/L, even under cold-weather conditions. It is noted that this reduction was achieved in House 008 by treatment of the basement alone, without having to insert suction pipes under the adjoining slab on grade. This result confirms the earlier observation that, when communication under the basement slab is good, it might not always be necessary to treat the adjoining wing. In the case of House 096, the basement DTD system and the slab on grade SSD system were not tested separately, so that it cannot be determined whether the entire house might have been treated through the DTD system in the basement alone.

The suctions developed in these SSD + DTD systems are summarized in Table 22. As expected, the suctions developed in the passive stacks in House 096 were fairly low -- essentially zero in the DTD stack from the sump, and no greater than 0.12 in. WG in the SSD pipes under the slab on grade when the furnace was operating and thus enhancing the natural suction by the flow of hot combustion products up the flue.

The suctions shown for the active system in House 008 are the classic example of the case where there is good communication and an effectively-installed system: suctions in the vicinity of 1 in. WG in the piping, and suctions above 0.1 in. WG under the slab at remote locations. The suction field extension for the active system in House 096 appears poor; combined with the relatively low suctions in both the SSD and DTD piping, it suggests significant air leakage into the system from some source, and perhaps limited communication. It is interesting to note that high radon reductions were achieved despite the low sub-slab suction measurements; perhaps the suction field was extending sufficiently well through the drain tiles (away from where the sub-slab pressure

TABLE 22. SUCTIONS DEVELOPED BY SSD + DTD SYSTEMS

House	Stack Suction (in. WG)	Sub-Slab Suction (in. WG)
Passive system		
096	-0.015[1] to -0.12[2] (SSD pipes - SOG)[3] 0.0 to 0.001 (DTD pipe - sump)[3]	--
Active systems		
008	-1.1 (DTD pipe)	-0.89 (1 ft from SSD pipe)
	-1.0 (SSD pipe)	-0.33 (22 ft fr. SSD & DTD)
096	-0.032 (DTD pipe)	0.0 (bsmt, 2 ft from sump)
	-0.24 (SSD pipes)	
126	-1.85 (SSD pipe)	-0.21 (1 ft from SSD pipe)
		-0.003 (4 ft from SSD pipe)
		0.0 (8 ft from SSD pipe)
	-0.055 (DTD pipe)	-0.026 (3 ft from DTD pipe)
		-0.005 (20 ft fr. DTD pipe)

[1] Suction in pipes under slab on grade, with central furnace not operating.

[2] Suction in SOG pipes with furnace operating.

[3] Weather conditions: 40 °F, calm

measurements were made), treating the major entry routes around the wall/floor joint and the block foundation wall. The suctions in House 126 show that the SSD fan was operating at essentially a stall condition (maximum suction in the piping, only 3 cfm flow); and the sub-slab suction field does not extend far from the suction pipe. These results suggest poor communication under the original basement slab. On the other hand, the low suctions and high flows in the DTD system indicate excessive air leakage into that system, much of it no doubt from the above-the-slab drain tile segment. But this low suction in the system piping nevertheless creates a reasonably good suction field under the slab for the new basement extension, probably from the good layer of aggregate placed under the new slab. It is of interest to note that fairly high radon reductions in House 126 were achieved even though only the new part of the basement slab had been depressurized by the active system. In fact, testing indicated that the basement radon levels remained low even when the SSD system in the original basement was turned off (with the DTD system in the extension on). This suggests that the major source of radon entry had been the original crawl space, and that this source was effectively treated when the crawl was paved and the DTD system operated.

11.3.2 Sub-Slab Plus Sub-Liner Depressurization

The performance of the passive SSD + SLD system in House 074 is summarized in Table 23, and the performance of the active systems in Houses 074 and 163 is summarized in Table 24.

TABLE 23. PASSIVE SUB-SLAB + SUB-LINER DEPRESSURIZATION RESULTS

House	House Type	Test Stage	Story	Radon Level (pCi/L) Before	Radon Level (pCi/L) After	% Reduction
074	B+CS	1	B	11.4-27.8	10.7-11.6	0 - 30
074	B+CS	1	LA	13.0	No data	Unknown

TABLE 24. ACTIVE SUB-SLAB + SUB-LINER DEPRESSURIZATION RESULTS

House	House Type	Test Stage	Story	Radon Level (pCi/L) Before	Radon Level (pCi/L) After	% Reduction
074	B+CS	2	B	11.4-27.8	3.8- 6.0	20 - 85
074	B+CS	2	LA	13.0	2.5- 4.2	About 70
163	B+CS	1	B	19.1-31.0	0.8- 4.8[1]	75 - 95
163	B+CS	1	LA	13.1-18.5	<0.1- 1.0[1]	92 - 98

[1] Fan at reduced power during this measurement.

The passive system in House 074 was ineffective. This is not surprising, in view of the poor (uneven) communication that was subsequently identified under the basement slab, and in view of the reduced passive suction in the sub-liner stack caused by its being located outdoors. In addition to performing poorly, this system had the added problem that moisture in the soil gas condensed in the wood stove flue that was used as the passive stack for the SSD system.

When the system in House 074 was activated, a more significant radon reduction was observed. However, the percentage reduction was relatively low for an active system (20 to 85%), and the residual radon concentrations were still not consistently below 4 pCi/L either in the basement or upstairs. It was subsequently determined that communication under the basement slab was uneven, and that the relatively poor performance resulted because the suction field was not extending to some portions of the basement slab.

The performance of the active system in House 163 was good. The higher post-mitigation measurements shown for this house in Table 24 result because some of the cold-weather measurements were made with the fan at reduced power. Operation of the fan at full speed reduced concentrations below 1 to 2 pCi/L.

The suctions developed by these systems are presented in Table 25. These are consistent with the observed radon results. The passive system in House 074 did not depressurize the basement sub-slab at a distance of about 10 ft from the SSD pipe; moreover, the SLD stack was not depressurized at all (since there was no wind, and since the thermal stack effect is lost when the passive stack is outdoors). Thus, the poor performance of this passive system is not surprising. While there were no pressure/flow measurements made during this study with the active system in House 074, later

TABLE 25. SUCTIONS DEVELOPED BY SSD + SLD SYSTEMS

House	Stack Suction (in. WG)	Sub-Slab Suction (in. WG)
Passive system		
074	+0.005 to +0.008 (bsmt SSD pipe)[3] -0.002[1] to -0.029[2] (SLD stack)[3]	+0.003 (10 ft fm. SSD pipe)
Active systems		
074	No data	No data
163	-0.80	-0.56 (2 ft from SSD pipe) -0.06 (10 ft from SSD pipe) 0.0 (30 ft from SSD pipe) 0.0 (5 ft from pipe in different direction)

[1] Without the wood stove operating.
[2] With the wood stove operating.
[3] Weather conditions: 35 °F, calm

measurements showed that the active suction field did not extend underneath the entire slab, explaining the relatively poor results with the active system in this house. While the suction measurements in House 163 suggest some unevenness in the suction field distribution under the basement slab, and failure of the suction field to extend even two-thirds of the way across the basement from the SSD pipe, reasonably good reductions were achieved nevertheless. This problem with the suction field undoubtedly explains why performance dropped when the fan power was reduced, as mentioned earlier.

11.3.3 Sub-Slab Plus Block Wall Depressurization

The performance of the passive SSD + BWD systems in Houses 069 and 106 are presented in Table 26. The performance of the active systems in those two houses is summarized in Table 27.

TABLE 26. PASSIVE SUB-SLAB + BLOCK WALL DEPRESSURIZATION RESULTS

House	House Type	Test Stage	Story	Radon Level (pCi/L)		% Reduction
				Before	After	
069	B+CS	2	B	13.2-20.0	8.2-11.3	15 - 75
069	B+CS	2	LA	8.5-13.2	5.3- 6.6	40 - 60
106	B+CS	2	B	19.2-58	7.1- 8.6	40 - 85
106	B+CS	2	LA	7.1-18	4.1- 5.7	30 - 80

TABLE 27. ACTIVE SUB-SLAB + BLOCK WALL DEPRESSURIZATION RESULTS

House	House Type	Test Stage	Story	Radon Level (pCi/L)		% Reduction
				Before	After	
069	B+CS	3	B	9.8-20.0	0.2- 1.3	87 - 99
069	B+CS	3	LA	5.6-13.2	0.3- 1.3	77 - 98
106	B+CS	3	B	7.9-58	~0.1	99
106	B+CS	3	LA	3.2-18	<0.1	>97

Again, the results from the passive systems appear to provide moderate radon reductions throughout the house, as shown in Table 26. It is of interest to compare the passive SSD + BWD performances in this table with those achieved in these houses during Stage 1 with passive SSD by itself (Table 11). This comparison shows that, in House 069, there was no improvement resulting from the addition of the BWD component (and perhaps even some loss of performance); for example, 40 to 70% reduction in the basement with passive SSD only becomes 15 to 75% with the combined system. In House 106, however, there would appear to be possibly some improvement; 0 to 50% reduction in the basement with passive SSD only becomes 40 to 85% with SSD + BWD.

It is noted that the BWD systems in these houses treated only one of the basement walls (the one between the basement and the adjoining wing in each case). Possibly better passive results might have been achieved if more walls had been treated.

No system or sub-slab suctions/flows were measured with the Stage 2 passive SSD + BWD systems in place. Thus, it is not possible to compare these suctions with those reported in Table 12 for the Stage 1 SSD-only systems. It might be expected that, with the addition of the air inflow via the block wall pipes, the magnitudes of the piping and sub-slab depressurizations might have been reduced somewhat when the BWD component was added.

As shown in Table 27, activation of these SSD + BWD systems in both cases reduced the houses below 2 pCi/L on both stories during cold weather. Both houses are thought to good aggregate. Moreover, treatment of the block stem wall between wings might not only have treated this radon source, but also have provided some soil depressurization under the adjoining wing. Since the active systems were not tested with only the basement SSD in operation, it cannot be determined whether active SSD in the basement alone might have treated the entire house without the BWD component.

No suction/flow measurements were made in House 069 with the active SSD + BWD system in operation. In House 106, suctions of 0.36 in. WG were measured in the SSD pipe, and 0.20 to 0.22 in. WG were measured in the two legs tapping into the block wall. Because of the air flow into the system from the block wall, suctions were lower than the 1-plus in. WG that is commonly measured in pure SSD systems with these 270 cfm fans. Depressurizations under the basement slab with the active system at House 106 were excellent, consistent with the owner's report that 4 in. of aggregate had been placed under the slab when the house was built; sub-slab depressurization was 0.24 in. WG at a distance of 2 ft from the SSD pipe, and 0.12 in. WG at the most remote corner of the basement, 25 ft away.

11.4 COSTS

The costs for the four passive combined-depressurization-system installations ranged from $2,040 to $4,980, and averaged $2,910. The cost of converting these four passive systems to active systems averaged $875. The installation costs for the seven active combined depressurization systems ranged from $2,620 to $6,350, and averaged $3,610.

CHAPTER 12

QUALITY ASSURANCE PRACTICES

12.1 INTRODUCTION

The Quality Assurance Project Plan (QAPP) for this project was completed in July 1987. Information on quality assurance and quality control procedures was presented in the QAPP, including sampling procedures, data reduction methods, quality assurance (QA) goals, and assessments of data quality. The QA practices followed for long-term, short-term, and grab measurements are presented below.

12.2 LONG-TERM RADON MONITORING

Long-term (3-month) radon measurements were taken with alpha-track detectors in duplicate (and in triplicate in several locations), by taping together the two detectors and deploying them as a pair. Radon levels were calculated by averaging the radon levels reported by the laboratory for the two detectors.

12.2.1 Precision

The precision of each set of detectors was estimated by calculating the relative percent difference (RPD). (For triplicates, the relative standard deviation (RSD) was calculated.) QA goals for the RPDs were established in the QAPP and were separated into four ranges by radon level (see Table 28). The precision goal was based on the assumption that precision increases as the measured radon concentration increases. The QA goals for precision were 100% RPD for radon levels below 2 pCi/L, 40% RPD for levels between 2 and

4 pCi/L, 25% RPD for levels between 4 and 20 pCi/L, and 15% RPD for levels greater than 20 pCi/L. For the 62 sets of detectors that had radon averages less than 2 pCi/L, 60 sets had RPDs that were below 80%, and were thus within the QA goal. The data for the two sets of detectors that were above 100% were discarded. For the 32 sets of detectors that had averages between 2 and 4 pCi/L, 26 sets had RPDs less than or equal to 40%, meeting the QA goal. The other 6 sets of detectors had RPDs outside the QA goal and were discarded. For the detectors in the 4 to 20 pCi/L range, 27 of the 34 sets had RPDs within the 25% QA goal. Based on a review of the RPDs, it was observed that the precision actually achieved was somewhat less than originally expected. Due to this observation, the QA requirement was raised to 33%. This modification did not limit the attainment of the project's objective of measuring the performances of the mitigation systems. Following this modification, the data for 32 of the 34 detector sets in the 4 to 20 pCi/L range were judged to be valid. The data for the other 2 sets of detectors were unusable and were discarded. The RPDs of the two discarded data sets were 54% and 116%. None of the 257 detectors sent to the laboratory had radon levels reported above 20 pCi/L.

TABLE 28. LONG-TERM MONITORING PRECISION (RPD)

	< 2 pCi/L	2 to 4 pCi/L	4 to 20 pCi/L	> 20 pCi/L
QA Goal	100%	40%	25%	15%
Actual Performance	80%	40%	32%	N/A

12.2.2 Accuracy

The accuracy of this sampling method was measured by sending "blind" alpha-track detectors spiked with a known concentration of radon to the analytical laboratory. Two groups of 6 to 8 detectors were sent for exposure in EPA's radon test chamber in Montgomery, Alabama. One group of detectors was exposed to a radon level of 99.5 +/- 2.5 pCi/L for 7 days, or 696 pCi-day/L. The second group was exposed to a radon level of 98.9 +/- 2.4 pCi/L for 3 days, or 297 pCi-day/L. A single spiked detector for one of the two groups was sent to the laboratory along with each batch of detectors retrieved from the 19 houses. For the first group of spikes (696 pCi-day/L), the accuracy for 7 of the 8 detectors was within the 25% bias QA goal. Only 3 of the 6 spikes from the second group (297 pCi-day/L) were reported within 25% bias of the actual value, and the average accuracy of all 6 detectors was 38% bias. For a 90-day exposure period, the 297 pCi-day/L spikes represent a radon level of 3.3 pCi/L, and an average accuracy of 38% represents a radon level of 3.3 +/- 1.3 pCi/L (2.0 pCi/L or 4.6 pCi/L). Therefore, the average value reported by the laboratory was only off the actual value by 1.3 pCi/L, which does not represent a large error in the radon level or effect the accomplishment of the project's objectives.

12.2.3 Completeness

Of the 257 alpha-track detectors sent to the laboratory, 234 detectors initially deployed generated valid data, representing a completeness of 91%. Twenty of the 257 detectors did not meet precision (RPD) QA requirements, one was received damaged, and two detectors were lost by one of the homeowners while moving. Although the QA goal of 95% had not been met, most of the 23 invalid detectors were for sampling periods that overlapped two different radon mitigation phases. As such, these data could not be used to calculate mitigation system performances anyway, and the results of the project were thus not significantly impacted.

12.2.4 Blanks

A blank (unexposed) alpha-track detector was included with each batch of detectors submitted to the laboratory for analysis. Nine of the 13 blanks were reported with less than 0.3 pCi/L, and all were below the 1.0 pCi/L QA goal.

12.3 SHORT-TERM RADON MONITORING AND GRAB SAMPLING

Pylon AB-5 continuous monitors equipped with 285 mL Lucas scintillation cells were used to measure short-term (2- to 4-day) radon levels and to obtain radon grab samples.

12.3.1 Calibration

Each of the Pylon units (i.e., the counter/scalers, excluding the Lucas scintillation cells) were initially calibrated at the start of the sampling program, by setting the high voltage and discriminator to their optimum operating settings. Specifically, the counts per minute, as a function of the high-voltage potentiometer setting, were recorded for the following conditions:

- the Pylon unit background, i.e., the counts per minute (cpm) recorded when there was no cell in the unit, and hence when the detector should have been receiving no scintillations at all.
- the Pylon unit with a standard check cell containing a thorium -230 source, delivering a known number of counts per minute.

Ideally, the cpm as a function of potentiometer setting should also have been recorded with one of the Lucas cells, containing an aged sample of radon-containing gas; this would have revealed any differences in the cpm-vs.-voltage-setting that might result from any slight differences between the characteristics of the check cell and the Lucas cells. Such measurements with a Lucas cell were not made, since it was felt that a sufficiently accurate setting could be obtained from the background and check-cell measurements. The potentiometer for each Pylon unit was then placed at that setting where: a) the check-cell cpm-vs.-voltage curve had distinctly flattened out; and b) the background cpm-vs.-voltage curve had not yet begun to rise.

This calibration was subsequently repeated on an annual basis, and after instrument repairs.

Scintillation cell yields, independent of the Pylon (counter/scaler) units, were determined in July 1987. All of the Lucas cells used in this project were shipped to the Department of Energy chamber in Grand Junction, Colorado, where they were filled with samples of a known radon concentration. These cells were then shipped to the Arix offices in Pottstown, Pennsylvania, for counting on a counter/scaler at that location. The yield factors for these cells -- i.e., the cpm apparently delivered for a given pCi/L in the cell -- were found to range from 1.10 to 1.55.

A more accurate figure might have been obtained if the yield factor had been determined for the combined Pylon-plus-Lucas-cell system (i.e., for the individual Lucas cell on the individual Pylon unit to which it would be dedicated). However -- since the Pylon background, the Pylon check-cell counts, and the individual Lucas cell yield factors had all been measured -- it was felt that the Pylons and cells had been adequately calibrated for the purposes of this project. This approach also enabled Lucas cells to be interchanged between Pylon units, which facilitated rapid movement of the detectors between houses.

To confirm that the monitors were performing properly throughout the project, background and source check measurements were repeated on each unit, each time that data were downloaded from the unit.

Typically, when the Pylon unit was retrieved from one of the houses, the standard check cell was counted. The Lucas cell which had been on the unit was removed, and replaced with a new cell which had been flushed with outdoor air or nitrogen at least 8 hours previously. This "zero" cell would then be counted for some period, usually at least an hour while the unit was being moved between houses. This provided a combined cell-plus-detector background count. The check-cell and combined-background readings were tracked to ensure that calibration was not changing during the conduct of the project.

At the beginning of the project, the flow rates of the pumps in the Pylon units were calibrated using a soap bubble flow meter.

12.3.2 Precision

Due to the large number of continuous radon measurements that had to be made during this project, and the relatively limited number of Pylons, duplicate measurements (two Pylons side by side) were not performed.

12.3.3 Accuracy

The accuracy of short-term radon measurements and grab sampling were measured in June 1988 through participation in Round 5 of EPA's Radon Measurement Proficiency Program, at the EPA radon test chamber in Montgomery, Alabama. To test the Pylons in the continuous monitoring mode, three detectors were exposed to 14.2 pCi/L of radon and measured radon levels of 12.6 pCi/L, 12.7 pCi/L, and 17.3 pCi/L. All three results were within the 25% QA goal, and had an average accuracy of 22% (see Table 29).

Four of the Pylon monitors were also tested in the grab-sample mode in the EPA chamber. Two of these monitors grabbed samples at a radon level of 13.9 pCi/L, and measured grab radon levels of 10.8 pCi/L and 11.5 pCi/L. Two other monitors grabbed samples at a radon level of 28.0 pCi/L, and measured 21.6 pCi/L and 24.0 pCi/L. All 4 grab radon tests had an average accuracy of 23%, and thus satisfied the 25% QA goal (see Table 30).

TABLE 29. SHORT-TERM MONITORING PERFORMANCE

	Accuracy	Completeness
QA Goal	25%	95%
Actual Performance	22%	94%

TABLE 30. GRAB SAMPLING PERFORMANCE

	Accuracy	Completeness
QA Goal	25%	95%
Actual Performance	23%	95%

12.3.4 Completeness

A total of 174 short-term continuous radon measurements were carried out during the course of this project. Of these tests, 164 provided data that were judged to be valid. This represents a completeness of 94%, which is slightly below the QA goals of 95%. The primary causes for the invalid tests were equipment malfunctions, in which the Pylon monitor counted in an erratic manner, the equipment used to transfer data stored in the Pylon to the portable computer was not operating properly, or the radon levels measured were highly suspect. In other situations, the homeowners had unplugged the instrument or had erased the data stored in the Pylon by tampering with the instrument. In one case, the data were accidentally erased by the instrument operator.

CHAPTER 13

REFERENCES

1. Findlay, W. O., A. Robertson and A. G. Scott, "Testing of Indoor Radon Reduction Techniques in Central Ohio Houses: Phase 1 (Winter 1987-1988)," EPA-600/8-89-071, July 1989 (NTIS No. PB89-219984).

2. Henschel, D. B., "Radon Reduction Techniques for Detached Houses: Technical Guidance (Second Edition)," EPA/625/5-87/019, January 1988 (NTIS No. PB88-184908).

APPENDIX A

MITIGATION SYSTEM INSTALLATION COSTS

APPENDIX A

MITIGATION SYSTEM INSTALLATION COSTS

House	Phase 1 Cost($)	Phase 2 Cost($)	Phase 3 Cost($)	Total Cost($)
004	2,700	630	--	3,330
008	2,255	850	--	3,105
010	700	740	850	2,290
011	1,730	--	--	1,730
032	1,435	460	--	1,895
041	1,550	--	--	1,550
047	1,300	--	--	1,300
054	2,170	935	--	3,105
061	2,145	460	--	2,605
069	1,780	445	810	3,035
074	4,980	1,370	--	6,350
076	1,190	550	--	1,740
079	2,145	470	--	2,615
096	2,400	460	--	2,860
106	1,510	530	860	2,900
110	1,265	--	--	1,265
126	2,620	--	--	2,620
143	1,400	--	--	1,400
163	4,380	--	--	4,380

Note: Due to the R&D component of this project, these costs are felt to be greater than would normally be the case if these systems were being installed commercially.

APPENDIX B

HOUSE DESCRIPTIONS

HOUSE 004

Basement Measurements	
Pre-mitigation Radon Levels	24.1-64.3 pCi/L
Stage 1 Post-mitigation Radon Levels	2.5-9.1 pCi/L
Stage 2 Post-mitigation Radon Levels	0.4-0.9 pCi/L

DESCRIPTION

This two-story house has an unfinished basement with poured concrete foundation walls. There is an adjoining slab-on-grade garage, which includes a laundry room and bathroom. The house was built in 1983, has wood siding, and is located in a hilly rural area a few miles west of Westminster, MD. There is a forced air electric heat pump system, a fireplace on the east side of the house, and another fireplace on the west side (see Figures 004-1 and 004-2).

The basement walls are poured concrete except where interrupted by two concrete block chimney structures, one each on the east and west sides. The basement walls are penetrated by a 1/2-inch well water pipe, a slab-on-grade water pipe, a 4-inch sewer pipe, and a slab-on-grade air duct. The basement slab was poured under the two chimney structures and has many hairline cracks. It is penetrated by an A/C condensate drain pipe, three separate sewer lines, three plumbing pipes, and four support posts. A hot water heater overflow pipe discharges to a 4-inch drain hole through the basement slab. Below the slab is a plastic vapor barrier and some crushed stone aggregate. The basement floor/wall joint is tight. The adjoining slab-on-grade garage has cracks, and was poured separately from the small (10 x 15 ft) laundry room and bathroom slab-on-grade section. Smoke tests indicated that operating the electric heat pump system depressurized the basement.

ACTION - HOUSE 004

Stage 1

The mitigation approach chosen for this house was a two-point passive sub-slab depressurization system combined with radon gas entry route sealing.

In November 1987, a 2-foot by 2-foot hole was made in the slab on the east side and another on the west side. To reduce pressure losses in the sub-slab depressurization system, eight cubic feet of soil, rocks and crushed stone aggregate were removed from each hole and replaced with 3/4-inch stone aggregate. A vertical 4-inch PVC suction pipe was inserted into each hole, and concrete was placed over the 3/4-inch stone to repair the two holes. The joints between the new concrete patches and the existing basement slab were tooled, and sealed with urethane caulk. The two suction pipes rose to the overhead joists, then were extended horizontally toward the center of the basement and connected to a passive stack, which was a 6-inch PVC pipe located twice as close to the east vent pipe as the west vent pipe. The 6-inch stack was routed to the attic through closets on the first and second floors. In the attic, the stack was insulated with fiberglass insulation. The stack was placed through the roof, attached to a 12-inch to 6-inch reducer, and connected to a 12-inch wind-driven turbine mounted on the rear side of the roof.

The basement slab cracks and floor/wall joints were ground out and sealed with caulk. Gun-grade (non-flowable) caulk was put into the routed floor/wall joint first, to serve as a backer material, which was then covered with flowable urethane caulk. The basement slab penetrations were sealed with urethane, and the wall penetrations were sealed with expandable foam. The A/C condensate drain pipe was rerouted to a portable sump pump unit, and the slab hole for the condensate drain was sealed. The electric heat pump return air duct joints were sealed with tape to minimize the suction of basement air into the system and to reduce basement depressurization.

In February 1988, Pylon monitors were used to measure short-term radon levels. With the passive system operating, the living room radon level was 8 pCi/L and the basement was 7 pCi/L. This represented a reduction over the living room pre-mitigation radon levels of 25 pCi/L and the basement level of 39 pCi/L. However, the effectiveness of the passive system could not be determined until long-term alpha-track detector data were available.

Alpha-track detectors were deployed from December 1987 to March 1988 to measure winter period radon levels. The living room radon level was 8.7 pCi/L and the basement was 9.1 pCi/L, confirming the February 1988 Pylon results. Although the passive depressurization system had reduced indoor radon levels, additional mitigation work would be needed to decrease the levels to below EPA's recommended average action level of 4 pCi/L.

Ventilation pipe suction and flow rate data were measured in March 1988 on a calm 30 °F day with the wind turbine stationary. Suction ranged from 0.013 to 0.023 inches of water in the east vent pipe, and from 0.008 to 0.013 inches of water in the west vent pipe. Any flow was below the detection limit (i.e., lower than 0.9 cfm) in each pipe. Due to the very low vent pipe suction and lack of flow, the passive system probably was not adequately influencing the sub-slab area; however, without sub-slab suction measurements, this could not be verified.

In June 1988, follow-up Pylon tests were performed to measure the relative effect of the passive system. During testing, the daytime outside temperature ranged from 85 °F to 100 °F. The first and second floor windows were open prior to testing, but were closed during testing to provide closed-house conditions. With the passive system off, the living room radon level was 0.7 pCi/L and the basement level was 7.6 pCi/L. This data indicated a significant difference between the living room and basement levels, and was surprising since radon values in these two areas were much closer in previous tests. The large difference in living room and basement radon levels was probably due to the house windows being open prior to testing and the warm weather during testing. When the windows were open, the radon in the living room was being ventilated. After the windows were closed, radon in the basement may not have flowed readily up to the living room, because with warm weather, there was no "stack effect" to act as a driving force. Therefore, living room radon levels remained low, despite elevated basement levels. When the passive system was turned on, the living room radon level averaged 1.4 pCi/L and the basement level averaged 3.3 pCi/L over approximately two days of Pylon testing. These data indicated that the living room radon level continued to be low, and that the basement level had been reduced by the passive system.

Alpha-track detectors were deployed from March 1988 to June 1988. The living room radon level was 3.9 pCi/L and the basement level was 6.8 pCi/L, according to these detectors. This represented a decrease over the winter quarter alpha-track detector levels, but probably resulted from normal seasonal variations. Due to the elevated basement radon level, further remediation work was required.

Stage 2

It was determined that there were no passive measures that could be implemented to enhance the performance of the existing system. For this reason, the passive depressurization system was activated.

In July 1988, a portion of the 6-inch stack in the attic was removed, and a Fantech in-line duct fan (270 cfm at zero back pressure) was installed to improve sub-slab suction. The wind turbine was left in place to reduce installation costs, since it was not expected to create much resistance to system air flow.

A fan control panel was installed in the basement, containing a power switch, an on/off light to indicate suction in the vent pipe, and a rheostat to adjust the fan speed.

Alpha-track detectors were deployed from September 1988 to January 1989. The living room radon level was 1.7 pCi/L and the basement level was 0.9 pCi/L, showing that the active depressurization system was effective.

In January 1989, Pylon measurements were made to measure the back-to-back, system on/off performance of the active depressurization system. With the fan off, the living room radon level was 6.7 pCi/L and the basement level was 11.7 pCi/L. With the fan on, the living room radon level decreased to 0.2 pCi/L and the basement level decreased to 0.4 pCi/L, demonstrating that operating the active system significantly reduced the radon levels.

Ventilation pipe suction and flow rate measurements were taken in May 1989 with the active depressurization system operating. In the east vent pipe, the suction was 1.52 inches water and the flow rate was 23 cubic feet per minute (cfm). In the west vent pipe, the suction was 1.51 inches water and the flow rate was 26 cfm. These data indicate that good suctions and reasonable flows were present in the two vent pipes. Also, a sub-slab suction field extension test was conducted to measure the influence of the active sub-slab depressurization system. With the active system operating, 0.750 inches of water of suction was measured in a sub-slab test hole located 10 feet from the east vent pipe, and 0.839 inches of water of suction was measured in a second sub-slab test hole located 22 feet from the east vent pipe. This data demonstrated that due to the active depressurization system, most, if not all of the sub-slab area was influenced.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 004

Gamma radiation levels measured in June 1987 were 1 uR/hr in the basement and 5 uR/hr in the garage. Therefore, the building materials for the house were not a source of radon gas. Freon gas communication tests were not performed due to equipment malfunction.

REMEDIATION SYSTEM - HOUSE 004

Stage	Installation Date	System Description
1	11/87	Passive two-point sub-slab depressurization and radon gas entry route sealing.
2	7/88	Active two-point sub-slab depressurization.

TEST DATA - HOUSE 004

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
-	10/87	43	Pre-mitigation	Living Rm	25	20-30
-	"	"	"	Basement	39	35-43
1	12/87	50	Passive on	Living Rm	13.1	10-19
1	"	"	"	Basement	7.8	6-10
1	2/88	42	Passive on	Living Rm	8	2-16
1	2/88	43	"	Basement	7	4-12
1	6/88	29	Passive off*	Living Rm	0.7	0.2-1.5
1	"	51	Passive on*	"	1.4	0.6-2.4
1	"	29	Passive off*	Basement	7.6	2.4-18.9
1	"	51	Passive on*	"	3.3	0.5-11.7
2	1/89	41	Fan off	Living Rm	6.7	4.7-8.5
2	"	"	Fan on	"	0.2	0.0-1.0
2	"	36	Fan off	Basement	11.7	8.1-14.9
2	"	39	Fan on	"	0.4	0.1-0.9

*Outside temperatures during the daytime ranged from 85°F to 100°F.

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	12/11/87-3/7/88	Living Room	8.2, 9.1
1	"	Basement	9.1, 9.1
1	3/7/88-6/22/88	Living Room	3.8, 3.9
1	"	Basement	6.7, 6.8
1,2	6/22/88-9/29/88	Living Room	0.8, 1.2
1,2	"	Basement	1.6, 2.0
2	9/29/88-1/6/89	Living Room	1.4, 2.0
2	"	Basement	0.8, 0.9
2	1/6/89-4/13/89	Living Room	< 0.3, 0.4
2	"	Basement	0.4, 0.5

PYLON GRAB SAMPLES - HOUSE 004

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
-	6/87	Pre-mitigation	Dining Room	9.3	0.065
-	"	"	Basement	15.1	0.181
-	6/87	Pre-mitigation	Slab penetration	658	-
-	7/87	Pre-mitigation	Garage	15.5	0.034
-	"	"	Basement	33.1	0.245
-	"	"	Slab penetration	30	-
1	3/88	Passive on	Basement	2.9	-
1	"	"	Fireplace ash trap	9.3	-
1	"	"	West vent pipe	2295	-

CHARCOAL CANISTER MEASUREMENTS

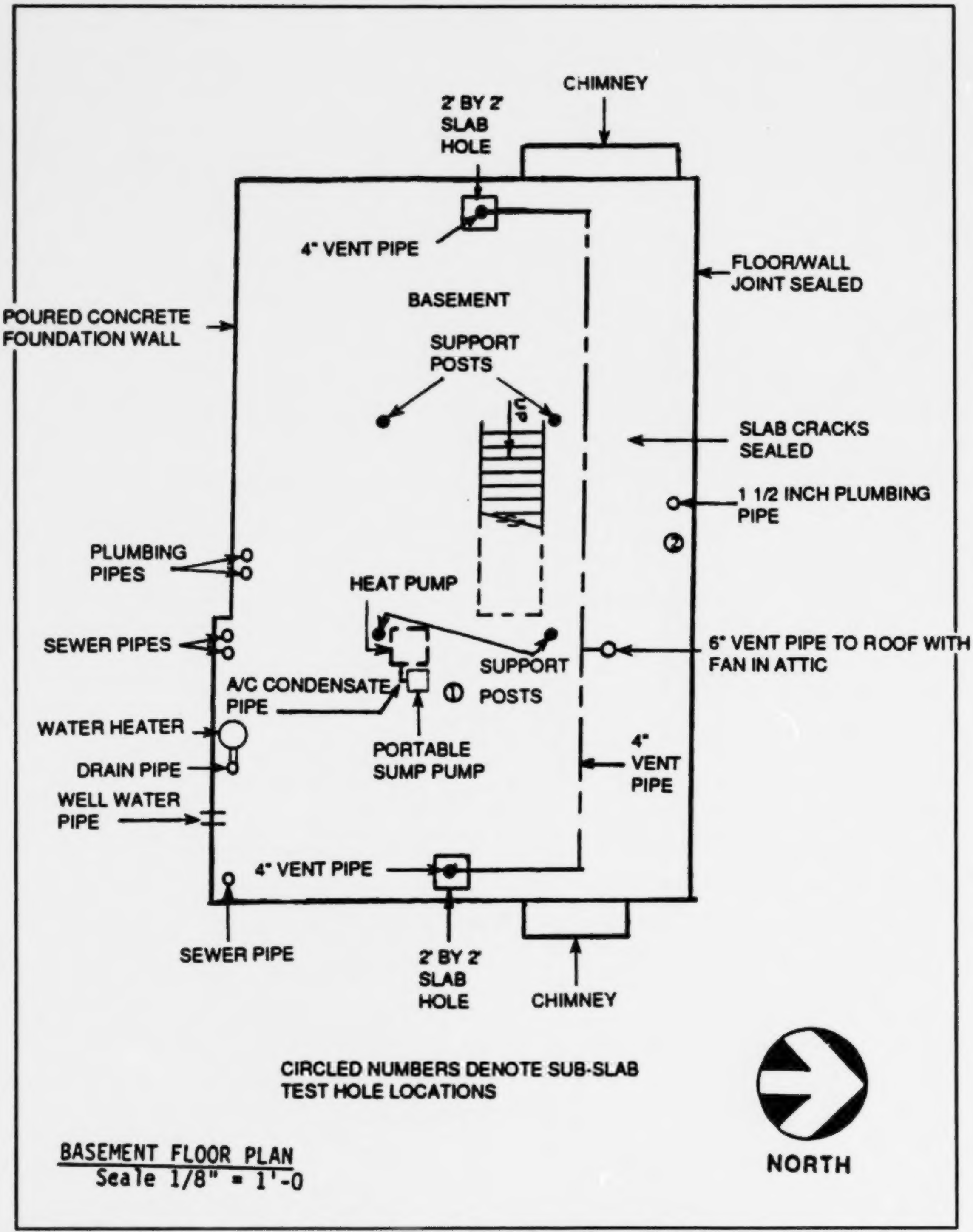
Date	Test Condition	Location	Radon Level (pCi/L)	Comments
2/87	Pre-mitigation	Family Room	37.5	Owner reported
"	"	Basement	64.3	"
8/87	Pre-mitigation	Basement	24.1, 24.5	

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Test Condition	Location**	Suction (inches H_2O)	Flow Rate (cfm)
1	3/88	Passive on*	East vent pipe	0.013 to 0.023	< 1.0
1	"	"	West vent pipe	0.008 to 0.013	< 1.0
2	5/89	Fan on	East vent pipe	1.52	23
2	"	"	West vent pipe	1.51	26
2	"	"	Slab hole 1	0.839	-
2	"	"	Slab hole 2	0.750	-

* No wind, turbine stationary.

** Numbers refer to sub-slab test hole locations (see Figure 004-1).


CHIMNEY
2' BY 2' SLAB HOLE
4" VENT PIPE
FLOOR/WALL JOINT SEALED
BASEMENT
POURED CONCRETE FOUNDATION WALL
SUPPORT POSTS
UP
SLAB CRACKS SEALED
1 1/2 INCH PLUMBING PIPE
②
PLUMBING PIPES
HEAT PUMP
SEWER PIPES
6" VENT PIPE TO ROOF WITH FAN IN ATTIC
SUPPORT POSTS
A/C CONDENSATE PIPE
①
WATER HEATER
PORTABLE SUMP PUMP
4" VENT PIPE
DRAIN PIPE
WELL WATER PIPE
4" VENT PIPE
SEWER PIPE
2' BY 2' SLAB HOLE
CHIMNEY
NORTH

CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS

BASEMENT FLOOR PLAN
Scale 1/8" = 1'-0

Figure 004-1. Basement floor plan for House 004

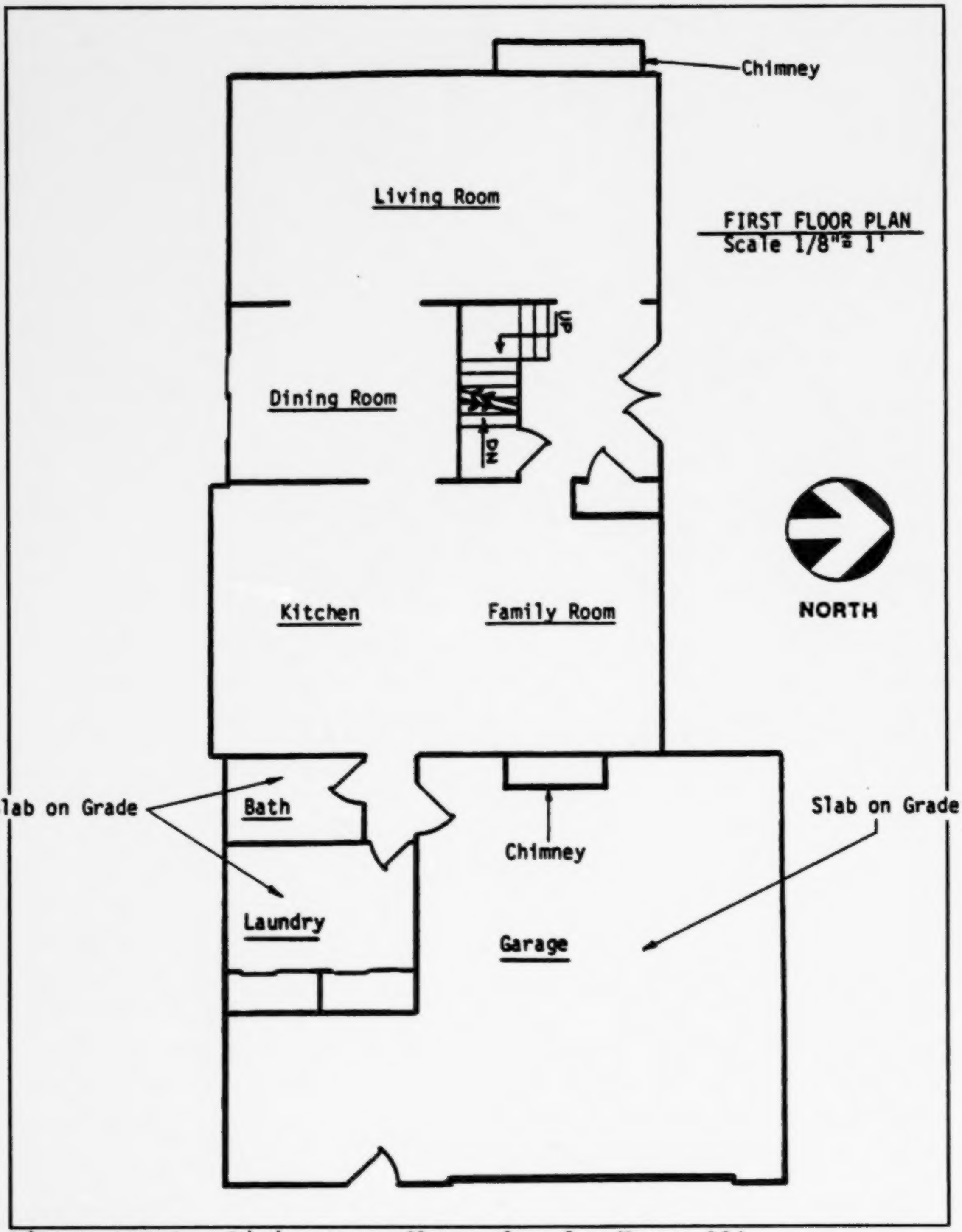

Chimney
Living Room
FIRST FLOOR PLAN
Scale 1/8"= 1'
UP
Dining Room
DN
NORTH
Kitchen
Family Room
Slab on Grade
Bath
Slab on Grade
Chimney
Laundry
Garage

Figure 004-2. Living area floor plan for House 004

HOUSE 008

Basement Measurements

Pre-mitigation Radon Levels	8.3-64.9 pCi/L
Stage 1 Post-mitigation Radon Levels	3.0-6.0 pCi/L
Stage 2 Post-mitigation Radon Levels	0.2-1.2 pCi/L

DESCRIPTION

This two-story house has an unfinished basement with poured concrete foundation walls, an attached slab-on-grade family room, and an attached slab-on-grade garage. It was built in 1985, has aluminum siding, and is located on flat land in a subdivision a few miles north of Columbia, MD. There is an electric forced air heat pump system, a whole house fan, an attic fan, and a family room fireplace that the homeowner uses approximately once a week during the winter (see Figure 008-1). The house is supplied with public water.

The basement walls are poured concrete and are located completely below grade. The basement walls are partially covered with insulation, no wall cracks are visible, and no wall penetrations exist. Part of the basement floor/wall joint has been sealed with caulk and the basement slab has a few cracks. The slab is penetrated by two support posts, a PVC pipe, and a sewer pipe. A plastic lined sump with an open bottom is located in the basement and is partially covered with a plywood board. The pedestal sump pump rests on the sump bottom and extends to several inches above the basement slab. An exterior basement stairwell floor drain and a single drain tile discharge to the sump. It could not be verified if the drain tile is interior or exterior. The A/C condensate drain pipe and hot water heater overflow pipe also empty into the sump. A heat pump air duct penetrates the west basement wall and leaks due to poor sheet metal work. The warm air supply duct branches into three ducts that pass under the family room slab-on-grade.

ACTION - HOUSE 008

Stage 1

A passive sub-slab depressurization system, in conjunction with sealing of suspected radon gas entry routes into the basement, was the mitigation system chosen for this house. While no basement sub-slab communication tests were performed to determine sub-slab conditions, a passive depressurization system was implemented due to the low basement radon level (8.3 pCi/L) measured with a Pylon in January 1988. A pre-mitigation Pylon grab sample measured 79.0 pCi/L in the air duct under the slab-on-grade and was a potential source of radon infiltration into the family room. Depressurization of the slab-on-grade area would be implemented if slab-on-grade radon levels continued to be high with the Stage 1 system in place.

In March 1988, a 6-1/2 inch diameter sub-slab suction hole was drilled through the east side of the basement slab. A portion of the hole was located above the basement wall footer, making it necessary to break away part of the concrete footer. A good layer of gravel aggregate was observed in the hole. Five gallons of gravel and concrete from the footer were removed from the hole to improve sub-slab suction. A 6-inch PVC ventilation pipe was placed inside the hole and was terminated flush with the bottom of the slab. A channel was chipped out of the existing slab around the pipe circumference, cleaned thoroughly, and filled with urethane sealant. The 6-inch diameter stack was extended up to the attic where it was insulated with fiberglass insulation. The pipe was placed inside a dry wall chase constructed on the first floor and concealed within a closet on the second floor. The 6-inch stack was placed through the roof, attached to a 12-inch to 6-inch reducer, and connected to a 12-inch wind-driven turbine mounted on the rear of the roof. Electrical wiring was installed in the attic for future use in the event that the passive system required activation.

The cracks in the interior of the basement slab were ground out and sealed with urethane. The wall/floor joint looked tight, and was not sealed. The sump hole was excavated to increase the depth, so that the top of the sump pump would be below the top of the slab. The plywood board that had covered the sump was discarded, and a new plywood cover was attached flush with the basement slab using metal bolts. The plywood cover was sealed to the slab with 24 mil PVC membrane and polyurethane sealant. The sump pump discharge pipe, pump electric wire, A/C condensate drain pipe, and water heater overflow pipe penetrated the plywood cover; seams around these penetrations were sealed with silicone. The ends of the A/C condensate drain pipe, the water heater overflow pipe, and the exterior stairwell drain pipe inside the sump were submerged in a plastic container full of water on the bottom of the sump. This container was intended to act as a trap, preventing soil gas in the sump from entering the basement through those drain lines. The sump pump discharge pipe, which extended outdoors through the basement wall, provided passive ventilation of the sump (assuming that the pump unit does not have much resistance to air flow, and that no water is present inside the sump to prevent air from flowing through the sump pump intake pipe).

The basement slab is penetrated by two support posts, a sewer pipe, and a PVC pipe. The slab was poured tight to the two support posts, and sewer pipe; therefore, these slab penetrations did not require sealing. The slab was not poured tight to the PVC pipe; however, this slab penetration was inadvertently overlooked during mitigation and was not sealed.

In April 1988, Pylon detectors were used to determine radon levels. With the passive system operating, the family room radon level was

1.8 pCi/L and the basement level was 3.5 pCi/L. These values represented a decrease over pre-mitigation Pylon levels (5.3 pCi/L in the family room and 8.3 pCi/L in the basement), but this apparent decrease may have been due to normal seasonal variations between January and April, rather than the passive system.

Suction and flow rates were measured in April 1988. On a windy day with the turbine spinning, suction inside the sub-slab vent pipe relative to the basement ranged from 0.010 to 0.100 inches of water, and flow in the pipe was not detected (less than 1 cubic foot per minute). Sub-slab suction was measured in a sub-slab test hole located 1 foot from the sub-slab vent pipe. The test hole suction ranged from 0.005 to 0.060 inches of water and was highly dependent on outside wind speed. Suction was also measured inside the sump located 24 feet away. The levels in the sump varied from a pressure of 0.005 inches of water to a suction of 0.020 inches of water. Higher suctions correlated to higher outside wind speeds. This data demonstrated that on a windy day, a major portion of the sub-slab area was being depressurized most of the time by the passive depressurization system.

Also, a Pylon grab sample on this test day measured only 1.8 pCi/L of radon in the basement, indicating that the passive system was very effective on windy days. Therefore, low radon levels were achieved by depressurizing the basement sub-slab area, and were independent of vent pipe flow rate. However, these data did not demonstrate the passive system's performance during cold weather or calm days.

In November 1988, Pylon tests were performed with the passive system off immediately followed by testing with the passive system on. The radon level with the passive system off was 3.8 pCi/L in the family room and 11.8 pCi/L in the basement. When the passive system was turned back on, the family room radon level was 1.8

pCi/L and the basement level was 3.0 pCi/L. This test, which was conducted during mild weather, indicated that the passive depressurization system had reduced the radon levels.

Alpha-track detectors were deployed from August 1988 to November 1988, and provided a more accurate measure of long-term radon levels. The family room alpha-track detector measured 3.1 pCi/L. However, the average radon level in the basement was 5.3 pCi/L, which was above EPA's recommended average action level of 4 pCi/L. Due to the elevated basement radon level during mild weather and the higher radon levels anticipated for the upcoming cool weather, additional mitigation activities would be required.

Stage 2

In December 1988, a sump depressurization pipe was installed that accessed the single drain tile (may have been interior or exterior). The combined SSD and DTD system was activated. A 4-inch PVC depressurization pipe was inserted into the plywood sump cover and sealed. The 4-inch suction pipe was routed to the east side of the basement and attached to the existing 6-inch SSD stack. A portion of the 6-inch stack in the attic was removed, and a Fantech in-line duct fan (270 cfm) was installed. The wind turbine was left in place to minimize installation costs.

A fan control panel was installed in the basement, containing a power switch, an on/off light to indicate suction in the pipe, and a rheostat to adjust the fan speed.

A check valve was never installed on the sump pump discharge pipe and the sump vent system might be drawing in air from outside the basement. However, the performance of the active system was good.

In January 1989, Pylon tests were performed. With the fan off, the family room and basement radon levels were both 0.4 pCi/L. These low "pre-mitigation" radon levels were probably due to the fact that the active system had been operating for a month prior to this test, depleting the radon gas from the soil under the house. It is apparent that the recovery rate of sub-slab radon was not fast enough to show an increase in soil gas radon levels during the two day test period. With the active system on, the family room level was 0.1 pCi/L and the basement was 0.2 pCi/L, demonstrating that the basement radon levels were below 4 pCi/L.

Alpha-track detectors were deployed from November 1988 to February 1989. The first month of testing was with the Stage 1 system and the last two months were with the Stage 2 system. The family room radon level averaged 0.5 pCi/L and the basement averaged 1.2 pCi/L. These results were higher than the January 1989 Pylon results, and probably occurred because the passive system was in place during one third of the test period.

In May 1989, pressure field tests were conducted to determine the effect of the active depressurization system by measuring the pressure differential across the slab relative to the basement. With the fan on, suction in the SSD pipe relative to the basement was 1.01 inches of water, and suction in the sump suction pipe was 1.06 inches of water. Suction was 0.891 inches of water in a sub-slab test hole located 1 foot from the SSD pipe, 0.570 inches of water 18 feet from the SSD pipe, and 0.333 inches of water 20 feet from the SSD pipe. These data indicated that the active system was creating suction under most, if not all of the slab area.

PRE-MITIGATION DIAGNOSTIC TESTING

Gamma radiation levels measured in June 1988 were 5 uR/hr in the family room and 6 uR/hr in the basement. Freon gas communication tests were not performed.

REMEDIATION SYSTEM - HOUSE 008

Stage	Installation Date	System Description
1	3/88	Passive sub-slab depressurization and radon gas entry route sealing.
2	12/88	Active sub-slab depressurization and drain tile depressurization, via the sump.

TEST DATA - HOUSE 008

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
-	1/88	44	Pre-mitigation	Family rm (SOG)	5.3	3- 8
-	"	"	"	Basement	8.3	5-22
1	4/88	84	Passive on	Family rm	1.8	0.7-3.2
1	"	"	"	Basement	3.5	1.4-8.6
1	11/88	44	Passive off	Family rm	3.8	0.9-5.5
1	"	46	Passive on	"	1.8	0.6-3.6
1	"	44	Passive off	Basement	11.8	6.7-19.8
1	"	46	Passive on	"	3.0	0.9-8.5
2	1/89	45	Fan off	Family rm	0.4	0.0-0.6
2	"	"	Fan on	"	0.1	0.0-0.8
2	"	45	Fan off	Basement	0.4	0.0-0.9
2	"	"	Fan on	"	0.2	0.0-0.8

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	8/2/88-11/17/88	Family room	2.7, 3.5
1	"	Basement	4.5, 6.0
1,2	11/17/88-2/16/89	Family room	0.4, 0.5
1,2	"	Basement	1.1, 1.2

PYLON GRAB SAMPLES - HOUSE 008

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
-	6/87	Pre-mitigation	Family room	0.3	0.021
-	"	"	Basement	13.4	0.062
-	10/87	Pre-mitigation	Family room	4.0	0.034
-	"	"	Basement	18.0	0.078
-	"	"	Air duct under slab on grade)	79.0	-
1	4/88	Passive on	Basement	1.8	-
1	"	"	Air duct under slab on grade)	8.3	_
1	"	"	Passive SSD stack	472	-

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
<3/87	Pre-mitigation	Basement	64.9	Owner deployed
8/87	Pre-mitigation	Basement	11.9, 12.5	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Test Condition	Location**	Suction*** (inches H_2O)	Flow Rate (cfm)
1	4/88	Passive on*	SSD stack	0.010 to 0.100	< 1.0
1	"	"	Inside sump	-0.005 to 0.020	-
1	"	"	Test hole 1	0.005 to 0.060	-
2	5/89	Fan on	SSD pipe	1.01	-
2	"	"	Sump suction pipe	1.06	-
2	"	"	Test hole 1	0.891	-
2	"	"	Test hole 2	0.570	-
2	"	"	Test hole 3	0.333	-

* Windy during test and turbine spinning.

** Numbers refer to sub-slab test hole locations (see Figure 008-1).

*** "Negative suction" indicates area is pressurized relative to basement.

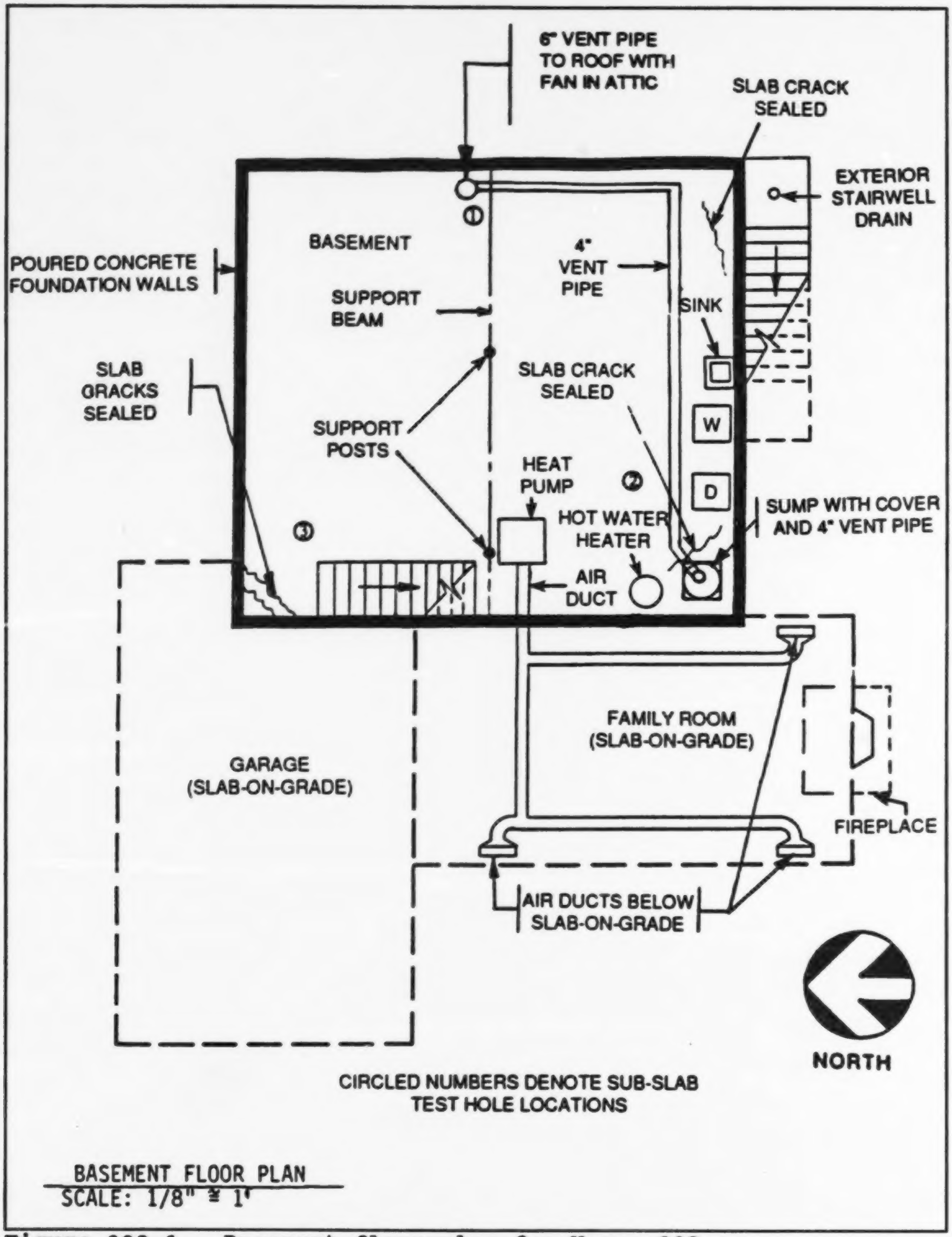

6" VENT PIPE TO ROOF WITH FAN IN ATTIC
SLAB CRACK SEALED
EXTERIOR STAIRWELL DRAIN
①
BASEMENT
POURED CONCRETE FOUNDATION WALLS
4" VENT PIPE
SUPPORT BEAM
SINK
SLAB GRACKS SEALED
SLAB CRACK SEALED
SUPPORT POSTS
W
HEAT PUMP
②
D
SUMP WITH COVER AND 4" VENT PIPE
③
HOT WATER HEATER
AIR DUCT
FAMILY ROOM (SLAB-ON-GRADE)
GARAGE (SLAB-ON-GRADE)
FIREPLACE
AIR DUCTS BELOW SLAB-ON-GRADE
NORTH
CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
BASEMENT FLOOR PLAN
SCALE: 1/8" ≅ 1'

Figure 008-1. Basement floor plan for House 008.

HOUSE 010

Basement Measurements	
Pre-mitigation Radon Levels	6.8-17.6 pCi/L
Stage 1 Post-mitigation Radon Levels	4.4-10.0 pCi/L
Stage 2 Post-mitigation Radon Levels	7.9-10.4 pCi/L
Stage 3 Post-mitigation Radon Levels	0.3-4.2 pCi/L

DESCRIPTION

This two-story house has an unfinished basement with concrete block foundation walls and an attached slab-on-grade garage. It was built in 1985, has vinyl siding, and is located on a hillside in a Mt. Airy, MD subdivision. Forced air electric heating is used and supplemented with a first floor fireplace. The fireplace does not rest on the basement block walls, and is supported by a separate brick foundation (see Figure 010-1).

The four basement walls are hollow block and have solid block caps. The homeowner reported that the basement wall exterior in contact with the soil has been waterproofed with tar. The basement walls are penetrated by a 4-inch sewer pipe, a 1 1/2-inch well water pipe, and electrical wires. There is a small hole in the southeast corner of the basement and a few gaps in the block walls where the concrete grout is missing. The floor/wall joint is approximately 0.1 inches wide and the basement slab has two cracks. The slab is penetrated by a 2-inch PVC pipe and four support posts. The A/C condensate drain pipe and exterior stairwell drain pipe discharge into a basement sump. The complete interior drain tile loop, which consists of 4-inch perforated pipe, also drains into the sump. The homeowner reported that there are 6 inches of crushed rock aggregate below the slab. During house diagnostics, a hole was drilled through the slab that provided evidence of aggregate and a plastic vapor barrier under the slab. Freon gas communication tests indicated moderate sub-slab communication.

ACTION - HOUSE 010

Stage 1

The mitigation approach chosen for this house was to seal suspected radon gas entry routes. This approach was chosen for this house because: the house did not have the complexity of an adjoining wing; the basement was unfinished, so that entry routes were accessible; and only a moderate radon reduction was needed, due to the only slightly elevated pre-mitigation radon levels (2.3 pCi/L in the living room and 6.8 pCi/L in the basement, according to Pylon measurements in November 1987.)

In January 1988, the floor/wall joint was ground out and sealed with flowable polyurethane caulk. The small hole, joint gaps, and minor cracks in the basement block walls were sealed with non-flowable urethane sealant. The hole in the block wall, where the electrical service penetrates, was sealed with expandable foam. The two interior basement slab cracks were ground out and sealed with flowable urethane. The seams between segments of the return air ducts for the forced air heating system were sealed with metal duct tape; other openings in the return ducts were closed with expandable foam.

A pre-fabricated PVC cover was installed on the sump. The ends of the A/C condensate drain pipe and the exterior stairwell drain pipe in the sump were submerged in a plastic cup filled with water, resting on the bottom of the sump, to act as a water trap which would prevent soil gas in the sump from entering the basement through these drain pipes. The sump was passively vented to the outside through the sump pump discharge pipe during periods when the sump is dry and no water is trapped above the check valve on the sump pump discharge pipe (assuming that the pump unit does not have much resistance to air flow).

Stage 1 Pylon measurements indicated that the basement still had elevated radon levels. This was confirmed by 3-month alpha-track detectors, deployed from February 1988 to May 1988. A 7.3 pCi/L basement average radon level was measured and showed that additional mitigative steps were needed.

Stage 2

The radon level inside the basement block wall that is adjacent to the slab-on-grade garage was measured to be 29.6 pCi/L with the Stage 1 system operating. This indicated that this block wall was a source of radon gas entry into the basement. To prevent radon from moving through the concrete block walls into the basement, a waterproofing sealant was painted on the wall surfaces.

Alpha-track detectors were deployed following Stage 2 work and measured a radon average of 10.0 pCi/L in the basement and 4.9 pCi/L in the living room. Therefore, the application of waterproofing paint to seal the block walls did not lower the house radon levels. This may have been due to the type of waterproofing paint used, since the paint appeared to be too thin to adequately seal the wall. Other potential radon gas entry routes into the basement that were not sealed were the utility pipe wall penetrations, the PVC pipe slab penetration, and the support post slab penetrations. However, these penetrations appeared to be sufficiently sealed with concrete during house construction and probably did not contribute to the basement radon concentrations.

Stage 3

An active depressurization system was installed on the sump in December 1988, to depressurize the perimeter of the sub-slab via the complete interior drain tile loop.

A hole was cut into the PVC sump cover, and a 4-inch PVC suction pipe was attached to the cover and sealed. The vent pipe ran upward from the cover, and a Kanalflakt T2 (270 cfm) in-line duct fan was installed on the pipe inside the basement. A 4-inch PVC pipe was attached to the fan exhaust, and extended upward to just below the basement ceiling; the pipe was then routed horizontally across the basement to the northwest corner. A hole was made through the foundation wall on the north side of the house, through which the 4-inch exhaust pipe exited the house. The pipe discharged to the outside at-grade. A screen was placed inside the pipe. Another hole was made in the sump cover to allow water that periodically leaked into the basement during heavy rain to drain into the sump. A small pipe was attached to this hole and extended down to the plastic cup trap inside the sump.

A fan control panel was installed in the basement, containing a power switch, an on/off light to indicate suction in the pipe, and a rheostat to adjust the fan speed.

Pylon measurements taken in January 1989 indicated that the basement radon level had been reduced to 0.3 pCi/L due to the active depressurization system.

Suction below the basement slab relative to the basement was measured in May 1989. Sub-slab suction 4 feet from the suction pipe was 0.221 inches of water, 20 feet from the suction pipe was 0.128 inches of water and 45 feet from the suction pipe was 0.112 inches of water. Therefore, a major portion of the sub-slab area was being influenced by the depressurization system.

PRE-MITIGATION DIAGNOSTIC TESTING

In July 1987, the gamma radiation level was 8 uR/hr in the first floor, 5-7 uR/hr in the garage, and 13-15 uR/hr in the surrounding soils. Freon gas communication tests were made in the basement in July 1987. Freon was injected into the sump and a vacuum drew suction on a hole approximately 35 feet away drilled in the basement slab. The freon was detected in the vacuum exhaust in approximately 4 minutes which indicated moderate sub-slab communication.

REMEDIATION SYSTEM - HOUSE 010

Stage	Date Installed	System Description
1	1/88	Radon gas entry route sealing.
2	7/88	Block wall painting/sealing.
3	12/88	Active interior drain tile depressurization via the sump.

TEST DATA - HOUSE 010

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
-	11/87	42	Pre-mitigation	Living rm	2.3	0-7
-	"	"	"	Basement	6.8	1-15
1	1/88	95	Post-mit.	Basement	10.0	1-16
1	2/88	48	"	"	8.1	1-16
1	3/88	93	"	"	4.4	0-11
1	5/88	93	"	"	9.8	4-18
1	"	"	"	Block Wall	29.6	12.8-59.0
2	11/88	93	Post-mit.	Living rm	4.7	0-8.8
2	"	"	"	Basement	7.9	1.2-13.7
3	1/89	40	Fan off	Living rm	3.9	2.1- 6.5
3	"	39	Fan on	"	0.0	0-0.4
3	"	39	Fan off	Basement	8.5	4.1-13.5
3	"	40	Fan on	"	0.3	0-1.3

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	2/8/88-5/4/88	Living room	4.1, 4.2
1	"	Basement	7.3, 7.3
1,2	5/4/88-8/9/88	Living room	2.7, 2.9
1,2	"	Basement	*
2	8/9/88-11/15/88	Living room	4.7, 5.0
2	"	Basement	9.7, 10.4
2,3	11/15/88-2/16/89	Living room	2.0, 2.2
2,3	"	Basement	2.8, 4.2

* Data outside QC goals.

PYLON GRAB SAMPLES - HOUSE 010

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	6/87	Pre-mitigation	Basement	17.3	0.136
1	3/88	Post-mitigation	Basement	0	--
1	"	"	Sump	76	--
1	"	"	In south block wall	1.0	--
1	"	"	Below slab	1814	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
Fall 1986	Pre-mitigation	First floor	11.8	Owner reported
"	"	Basement	17.6	"
8/87	Pre-mitigation	Basement	11.3-13.6	

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Location*	Suction (inches H_2O)	Flow Rate (cfm)
3	5/89	Active DTD pipe	0.510	140
3	"	Test hole 1	0.221	-
3	"	Test hole 2	0.128	-
3	"	Test hole 3	0.112	-

* Numbers refer to sub-slab test hole locations (see Figure 010-1).

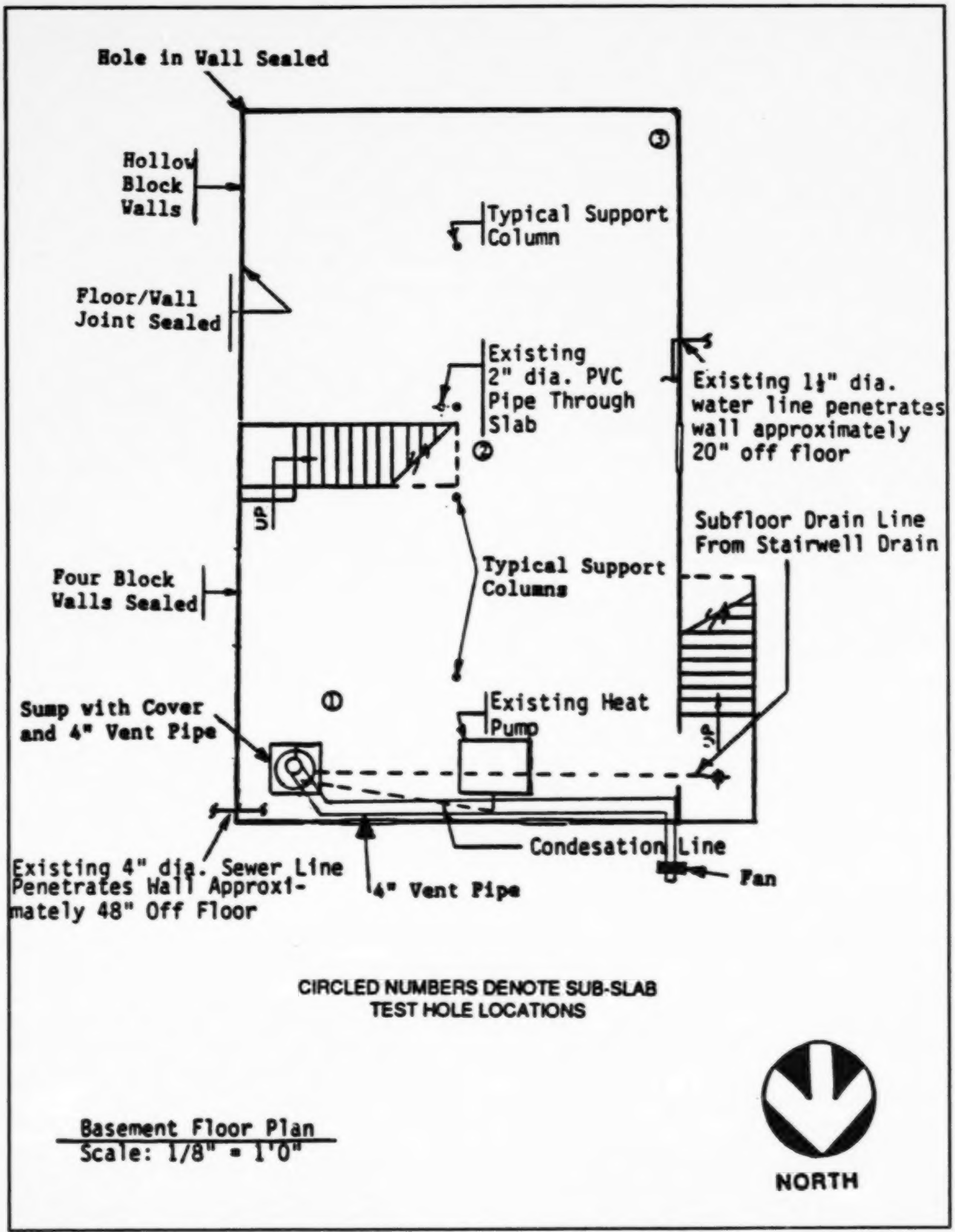

Hole in Wall Sealed
Hollow Block Walls
Typical Support Column
Floor/Wall Joint Sealed
Existing 2" dia. PVC Pipe Through Slab
Existing 1½" dia. water line penetrates wall approximately 20" off floor
UP
Subfloor Drain Line From Stairwell Drain
Four Block Walls Sealed
Typical Support Columns
Sump with Cover and 4" Vent Pipe
Existing Heat Pump
UP
Condesation Line
Existing 4" dia. Sewer Line Penetrates Wall Approximately 48" Off Floor
4" Vent Pipe
Fan
①
②
③
CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
Basement Floor Plan
Scale: 1/8" = 1'0"
NORTH

Figure 010-1. Basement floor plan for House 010

HOUSE 011

Basement Measurements	
Pre-mitigation Average Radon Levels	88.3-178 pCi/L
Stage 1 Radon Levels	0.1-3.5 pCi/L

DESCRIPTION

This is a split-level house: the first level is a walk-out basement, the second level slab-on-grade, and the third and fourth levels are above the other two. The house has hollow concrete block foundation walls with solid block caps, and an attached slab-on-grade sun room and patio. This house was built in 1983 and has brick face, wood, and cement exterior walls. The house is located in a rural area several miles north of Westminster, MD. There is an electric radiant heating system, a third floor fireplace, and a basement wood stove with no makeup air that is used during the winter (see Figure 011-1).

The basement block walls are finished with drywall and are mostly above grade. Prior to finishing with drywall, the 1/2-inch basement slab expansion joint was sealed by the homeowner, except behind the stairway. The basement slab has no cracks and is penetrated by two support posts. There is a slab-on-grade patio at the walk-out basement level. An interior perimeter drain tile system exists for the slab-on-grade and the basement slab; the drain tiles have two discharge pipes that drain to daylight on the east side of the house. There is a 4-foot concrete block stem wall between the basement and second level slab-on-grade. The second level is finished, has a plumbing rough-in for a future bathroom, and has an attached sun room. A plastic vapor barrier, 2 inches of styrofoam insulation, and 4 inches of stone aggregate is beneath the slab-on-grade. The whole house fan, when operated, creates a house suction of 0.150 inches of water.

ACTION - HOUSE 011

Stage 1

Due to the high pre-mitigation basement radon level of 88.3 pCi/L and slab-on-grade value of 43.1 pCi/L measured with the Pylon in November 1987, an active two-point slab-on-grade and two-point basement sub-slab depressurization system was chosen for mitigation. Since the basement block walls were primarily above grade, they were not expected to be a significant source.

In November 1987, two 4-1/2 inch diameter holes were drilled through the basement slab approximately 2 feet from the stem wall. The slab holes revealed aggregate below the slab. Two 4-1/2 inch diameter holes were also drilled through the stem wall to access the radon trapped below the slab-on-grade, revealing a crushed stone aggregate layer beneath the slab-on-grade. Also, the interior perimeter drain tile was visible in the north stem wall hole. A 4-inch diameter PVC suction pipe was inserted into each of the four holes (see Figures 011-1 and 011-2). Dampers were placed inside the 4 pipes. The pipes were connected to a common 4-inch diameter stack that was extended up through a chase to the attic. The stack was insulated in the attic with fiberglass insulation. A Fisher in-line duct fan (270 cfm) was installed in the stack within the attic. The stack was routed through the roof, and a rain hat was placed on top. The fan was set on high and the vent pipe dampers were adjusted to balance the flow rates. The slab hole in the future bathroom was sealed.

A fan control panel was installed in the laundry room, containing a power switch, an on/off light to indicate suction in the vent pipe, and a rheostat to adjust the fan speed.

Post-mitigation radon levels were measured with Pylon monitors in December 1987. With the fan on high, the radon value was 0.5 pCi/L in the second level laundry room and 0.1 pCi/L in the basement. Another Pylon test was performed with the basement wood stove being used during much of the test. Operation of the wood stove would tend to depressurize the basement and thereby increase radon entry into the basement. However, the basement radon level was 0.0 pCi/L, indicating that the wood stove did not have an adverse affect on the mitigation system.

Alpha-track detectors were deployed from December 1987 to March 1988. With the fan on high, the radon levels were 1.8 pCi/L in the laundry room and 0.9 pCi/L in the basement, demonstrating that the active vent system was very effective. These data also showed that the basement level was lower than the laundry room level, which is a reversal of the pre-mitigation condition. Based on this data, the active vent system seemed to have a greater impact on the basement than on the slab-on-grade.

In March 1988, basement sub-slab suction was measured in a test hole located approximately 18 feet from the two SSD suction pipes. Sub-slab suction relative to the basement ranged from 0.015 to 0.022 inches of water with the fan on high. The amount of suction decreased when the fan was lowered to medium, as would be expected. Dampering off the two stem wall vent pipes increased the sub-slab suction, which then ranged from 0.040 to 0.050 inches of water at the 18-ft test hole. Also, operation of the whole house fan had no affect on the sub-slab suction with the fan on high, but reduced the sub-slab suction with the fan on medium.

Suction pipe suction and air flow rate were also measured in March 1988. With the fan speed on high, the suction in the north vent pipe through the basement slab ranged from 0.054 to 0.065 inches of water and the flow rate was 26 cubic feet per minute (cfm); the north stem wall pipe suction ranged from 0.069 to 0.075 and the flow rate was 32 cfm; the south slab vent pipe suction ranged from 0.099 to 0.103 and the flow rate was 46 cfm; and the south stem wall vent pipe suction averaged 0.115 and the flow rate was 38 cfm. When the fan speed was set to medium, flow rate in the vent pipes decreased by approximately 65 percent on the average for 3 of the 4 pipes.

The fan was lowered to medium speed in the spring of 1988, to determine its affect on the radon levels. Alpha-track detectors were deployed from March 1988 to June 1988 to measure radon levels. The fan speed was on medium for most of this test period. The radon level was 8.2 pCi/L in the laundry room and 3.3 pCi/L in the basement. Therefore, the laundry room radon level was above EPA's recommended action level average of 4 pCi/L. Also, the laundry room radon level continued to be higher than the basement level. This may have been in part due to the slab-on-grade north vent pipe drawing soil gas from the slab-on-grade drain tile located very near to the north vent pipe.

In July 1988, the fan speed was reset to high. Radon levels were measured using alpha-track detectors from September 1988 to January 1989. The laundry room averaged 3.1 pCi/L and the basement averaged 1.9 pCi/L, demonstrating that the active depressurization system effectively reduces the house radon levels.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 011

In June 1987, the gamma radiation level was 8 uR/hr in the basement.

REMEDIATION SYSTEM - HOUSE 011

Phase	Installation Date	System Description
1	11/87	Active two-point slab-on-grade and two-point basement sub-slab depressurization.

TEST DATA - HOUSE 011

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
-	11/87	34	Pre-mitigation	Laundry (SOG)	43.1	10-103
-	"	"	"	Basement	88.3	33-157
1	12/87	45	Fan on high	Laundry	0.5	0-2
1	"	"	"	Basement	0.1	0-2
1	12/87	46	Fan on high*	Basement	0.0	0-1

*Wood stove was in use during much of the test.

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Condition	Location	Reported Rn for each Detector (pCi/L)
1	12/11/87-3/7/88	Fan on high	Laundry room	1.3, 2.2
1	"	"	Basement	0.6, 1.2
1	3/7/88-6/17/88	Fan on medium	Laundry room	7.9, 8.6
1	"	"	Basement	3.0, 3.5
1	6/17/88-9/29/88	Fan on medium/ high	Laundry room	1.0, 1.0
1	"	"	Basement	*
1	9/29/88-1/10/89	Fan on high	Laundry room	3.1, 3.1
1	"	"	Basement	1.8, 1.9

*Data outside QC goals.

PYLON GRAB SAMPLES - HOUSE 011

Stage	Date	Test Condition	Location	Radon Level (pCi/L)
--	6/87	Whole house fan off	Basement floor/wall joint	190
--	"	Whole house fan on	"	470
--	"	"	Second level slab penetration	60
--	"	Whole house fan off	Second level slab hole	90
1	3/88	Post-mitigation	Basement	0
1	"	"	Below basement slab	250

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
<3/87	Pre-mitigation	Laundry room (SOG)	135	Owner reported
"	"	Basement	178	"
8/87	Pre-mitigation	Basement	5.7, 7.2	

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Test Condition	Location*	Suction (inches H_2O)	Flow Rate (cfm)
1	3/88	Fan on high	North slab pipe	0.054 to 0.065	26
1	"	"	North stem pipe	0.069 to 0.075	32
1	"	"	South slab pipe	0.099 to 0.103	46
1	"	"	South stem pipe	0.115	38
1	"	Fan on medium	North slab pipe	0.004 to 0.014	N/A
1	"	"	North stem pipe	0.010 to 0.038	17
1	"	"	South slab pipe	0.013 to 0.018	10
1	"	"	South stem pipe	0.027 to 0.040	12
1	"	Fan on high	Test hole 1	0.015 to 0.022	--
1	"	Fan on medium	Test hole 1	-0.001 to 0.015	--
1	"	Fan on high**	Test hole 1	0.040 to 0.050	--
1	"	Fan on medium**	1	0.005 to 0.018	--
1	"	Fan on high***	1	0.013 to 0.028	--
1	"	Fan on medium***	1	-0.001 to 0.003	--

* Number refers to basement sub-slab test hole location (see Figure 011-1).

** With 2 stem wall vent pipes dampered off.

*** With whole house fan operating.

Negative suction indicates area is pressurized relative to house.

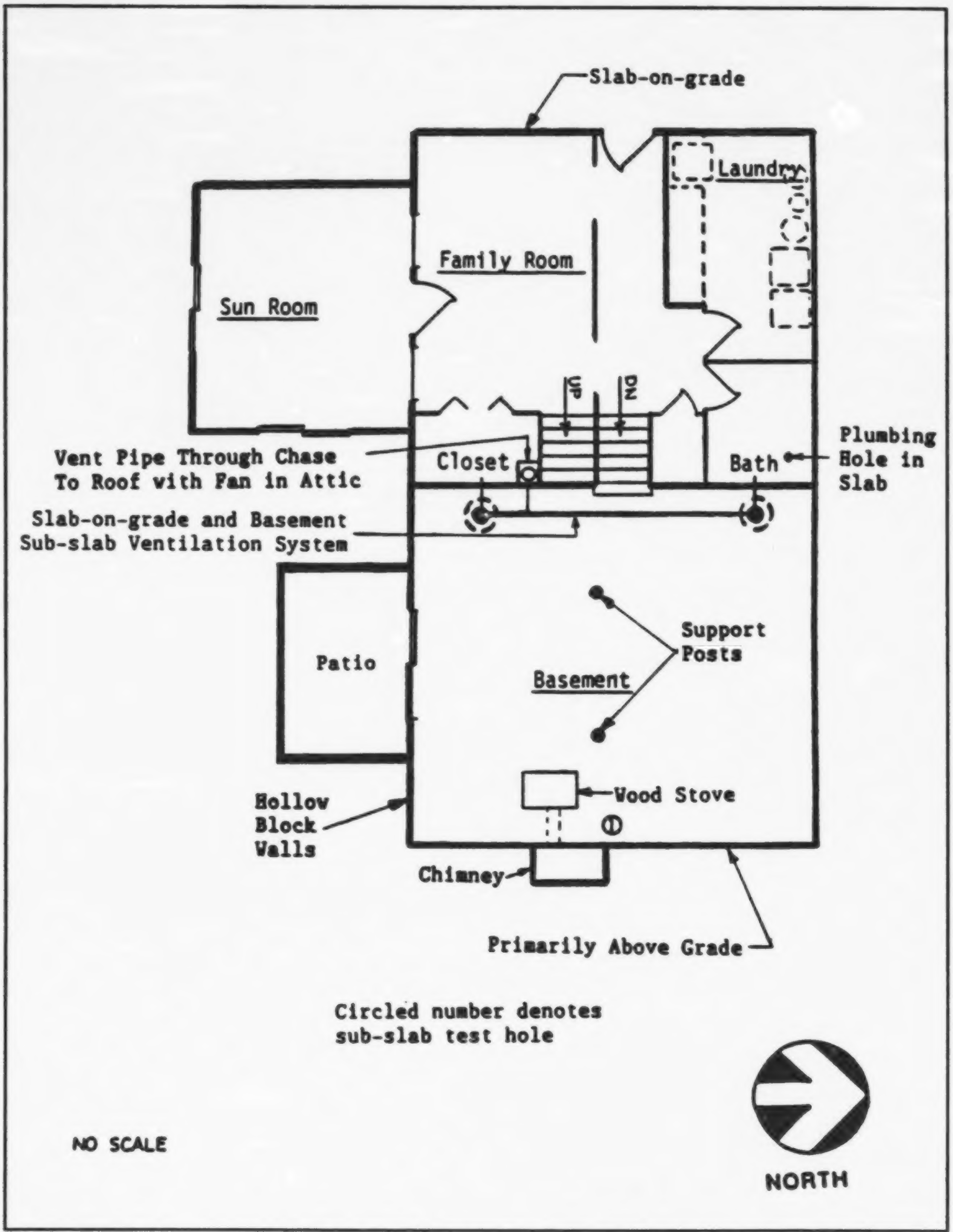

Slab-on-grade
Laundry
Family Room
Sun Room
UP
DN
Vent Pipe Through Chase
To Roof with Fan in Attic
Closet
Bath
Plumbing
Hole in
Slab
Slab-on-grade and Basement
Sub-slab Ventilation System
Patio
Support
Posts
Basement
Hollow
Block
Walls
Wood Stove
①
Chimney
Primarily Above Grade
Circled number denotes
sub-slab test hole
NO SCALE
NORTH

Figure 011-1. Basement and slab-on-grade floor plan for House 011

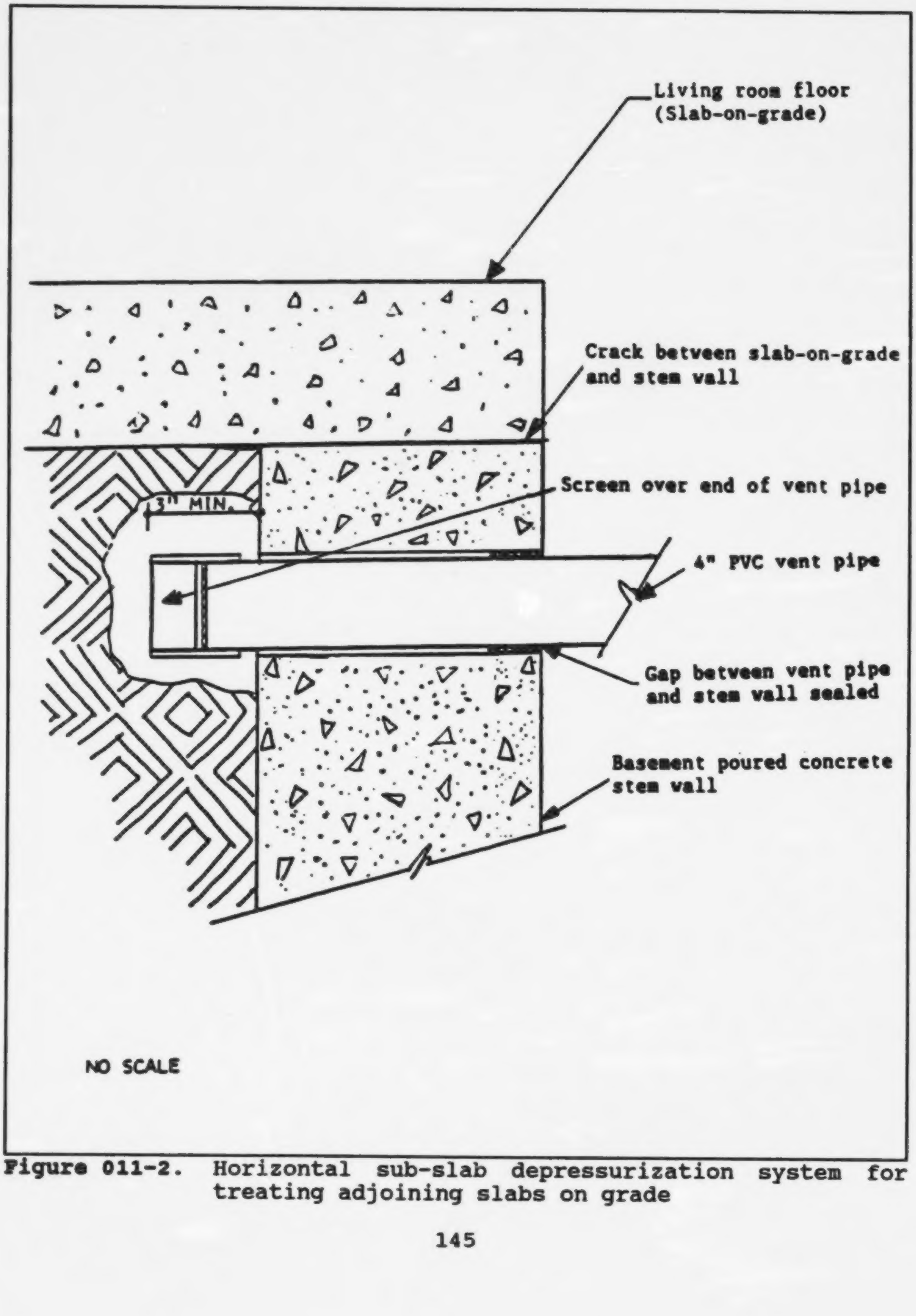

Living room floor
(Slab-on-grade)
Crack between slab-on-grade
and stem wall
Screen over end of vent pipe
3" MIN.
4" PVC vent pipe
Gap between vent pipe
and stem wall sealed
Basement poured concrete
stem wall
NO SCALE

Figure 011-2. Horizontal sub-slab depressurization system for treating adjoining slabs on grade

HOUSE 032

Basement Measurements	
Pre-mitigation Radon Levels	7.8-11.9 pCi/L
Stage 1 Post-mitigation Radon Levels	3.8-9.0 pCi/L
Stage 2 Post-mitigation Radon Levels	0.7-1.4 pCi/L

DESCRIPTION

This one-story house has a basement with hollow block foundation walls, and an adjoining slab-on-grade carport. It was built in 1980, has three aluminum siding walls, one brick wall, and is located in a hilly rural area several miles west of Damascus, MD. The heating system is an electric heat pump supplemented with a brick fireplace in the basement; the homeowner rarely uses the fireplace. The fireplace rests on top of the slab and has no outside source of combustion air (see Figure 032-1).

The concrete block basement walls have open top voids. A portion of the walls is finished with brick and panelling. The north and west basement walls have open top voids that are completely covered by sill plates. The south basement wall has a 2- by 4-inch sill plate that only partially covers the open top voids, and the east wall has no sill plate. The basement walls have a few cracks and are penetrated by a well water pipe and a 4-inch sewer pipe. The basement slab has several major cracks that total approximately 75 feet in length, and is penetrated by four support posts. An exterior stairwell is present with a "floor drain" on the bottom pad that drains to daylight in the front yard. There is a slab-on-grade carport on the west side and a small slab-on-grade porch in the rear. No perimeter drain tiles exist, and there is no basement sump. Water stains on the basement walls indicate a drainage problem.

ACTION - HOUSE 032

Prior to involvement in this project, the homeowner tested the effect on radon levels of opening several house windows. During a 9-month period in 1986, the homeowner left open three basement windows and the basement sliding glass door. During the summer portion of this test, the first floor windows also remained open. Alpha-track detectors for this period measured 6.2 pCi/L radon in the basement. This was an improvement over the radon level of 11.9 pCi/L measured subsequently in 1987 during closed-house conditions.

Stage 1

A passive sub-slab depressurization system, in conjunction with floor and wall crack sealing, was the mitigation system chosen for this house. A passive system was chosen due to the relatively low radon levels and the good sub-slab communication indicated by freon gas communication tests.

In March 1988, a 6-1/2 inch diameter hole was drilled through the basement slab to provide an access to the sub-slab, but no aggregate was present. Due to the lack of sub-slab aggregate, it was decided to cut a 2-foot by 2-foot hole in the slab so that a larger hole could be excavated under the slab. According to the homeowner, a rain storm during house construction caused mud to cover part of the aggregate. To reduce pressure losses in the system, eight cubic feet of mostly hard packed clay was removed from the 2-foot by 2-foot hole and replaced with 3/4-inch washed rock. A 6-inch PVC suction pipe was inserted into the hole, and routed directly up through a cold air return chase to the attic. In the attic, the stack was extended 4 feet horizontally before passing up through the roof. The stack was insulated in the attic. On the roof, the stack was connected to a 12-inch to 6-inch reducer, and attached to a 12-inch wind-driven turbine. The attic was pre-wired in the event that a fan was required later.

Several wide cracks in the basement slab were ground out and sealed with flowable urethane caulk. Also, two cracks in the south wall were sealed. The floor/wall joint was very tight and much of it was inaccessible. Therefore, the floor/wall joint was not ground out and sealed. During mitigation system installation, it was not noticed that many of the top blocks in the basement walls were open; thus, the top voids were not filled with expandable foam.

Average radon levels in the basement decreased as a result of the passive system, but were still elevated above EPA's recommended average action level of 4 pCi/L. Alpha-track detectors that were deployed from September 1988 to December 1988 measured 7.9 pCi/L in the basement. This is an improvement over the 11.9 pCi/L pre-mitigation level. Also, the dining room radon level dropped from 10.0 pCi/L to 5.6 pCi/L.

In April 1988, on a breezy day, suction in the passive sub-slab depressurization pipe ranged from 0.008 to 0.048 inches of water and the flow rate ranged from 0 to 2 cubic feet per minute (cfm). Pressure field extension tests were conducted on five sub-slab test holes. Suction relative to the basement was detected in all five test holes. This data indicated that a major portion of the slab was being depressurized. In spite of this, the basement radon level was still elevated (8.0 pCi/L).

Stage 2

Additional mitigation efforts were required to lower the radon to acceptable levels. Options considered included sealing floor/ wall joints, over-pressurizing the basement, and providing outside make-up air for the fireplace. Another improvement to the passive system would have been to seal the open top voids in the basement wall with expandable foam. Rather than attempt additional passive techniques that may not have been effective, the system was activated.

Converting the passive sub-slab depressurization system to an active system only required the removal of a portion of the 6-inch stack in the attic, and the installation of a Fantech Model R-150 (270 cfm) in-line duct fan at that position, using the wiring installed during Stage 1. The wind turbine was not replaced with a rain hat to minimize installation costs and was not expected to significantly impact the pipe air flow.

A fan control panel was installed in the basement. It contained a power switch, an on/off light to indicate whether the fan was drawing suction, and a rheostat to adjust the fan speed.

In December 1988, radon levels were measured using Pylon detectors. The basement level averaged 0.7 pCi/L and the dining room level was 1.3 pCi/L. These values were significantly lower than the pre-mitigation levels, and showed that upgrading the system from passive to active was effective.

Alpha-track detectors were deployed from December 1988 to March 1989. The radon levels were 1.2 pCi/L in the dining room and 1.3 pCi/L in the basement, demonstrating the success of the active system.

Suction below the slab relative to the basement was measured in March 1989. Sub-slab suction ranged from 0.160 to 0.409 inches of water in the five test holes. Two of the test holes were located at opposite basement corners, demonstrating that most of the basement slab was being depressurized.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 032

In July 1987, the basement gamma radiation level ranged from 9-10 uR/hr. Freon gas communication tests ere made on October 7, 1987 with two test holes approximately 30 feet apart. Freon was injected into one hole and was detected in the other hole after two minutes, which indicated good sub-slab communication. Also, a plastic vapor barrier was observed in one of the test holes.

REMEDIATION SYSTEM - HOUSE 032

Stage	Installation Date	System Type
1	3/88	Passive sub-slab depressurization and radon gas entry route sealing.
2	12/88	Active sub-slab depressurization.

TEST DATA - HOUSE 032

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
--	12/87	43	Pre-mitigation	Dining rm	10.0	4-18
--	"	43	Pre-mitigation	Basement	11.9	8-19
1	4/88	95	Passive on	Dining rm	3.1	0-7
1	"	"	"	Basement	3.8	1-6
1	6/88	40	Passive off	Dining rm	3.4	1.4-6.5
1	"	19	Passive on	"	2.2	1.0-3.2
1	"	38	Passive off	Basement	10.4	6.4-18.5
1	"	19	Passive on	"	7.1	4.8-9.3
1	12/88	93	Passive on	Dining rm	4.7	2.9-6.8
1	"	"	Passive on	Basement	5.7	3.8-7.4
2	12/88	40	Fan off	Dining rm	3.7	2.4-4.8
2	"	38	Fan on	"	1.3	0.9-2.3
2	"	40	Fan off	Basement	3.8	2.1-5.1
2	"	40	Fan on	"	0.7	0.3-1.1

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Test Condition	Location	Reported Rn for each Detector (pCi/L)
-	3/86-12/86	Basement and first floor windows open	Bedroom	4.1
-	"	"	Master bedroom	3.8
-	"	"	Living room	3.5
-	"	"	Basement	6.2
1	6/8/88-9/8/88	Post-mit.	Dining room	5.3,6.0
1	"	"	Basement	7.2,9.0
1	9/8/88-12/13/88	"	Dining room	5.3,6.0
1	"	"	Basement	7.3,8.4
2	12/13/88-3/15/89	"	Dining room	1.2,1.2
2	"	"	Basement	1.1,1.4

PYLON GRAB SAMPLES - HOUSE 032

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
-	6/87	Pre-mitigation	Living room	1.3	0.003
-	"	"	Basement	9.6	0.043
-	10/87	"	Living room	10.5	—
-	"	"	Basement (west)	14.3	—
-	"	"	Basement (east)	18.0	—
1	4/88	Passive on	Basement	5.2	—
1	"	"	Inside block wall (south)	20.6	—

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
3/86	Pre-mitigation	Living room	6.4	Owner reported
"	"	Basement	11.5	"
8/87	Pre-mitigation	Uncertain	7.8, 7.9	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS - HOUSE 032

Stage	Date	Test Condition	Location**	Suction (inches H_2O)	Flow Rate (cfm)
1	4/88*	Passive on	Vent pipe	0.008 to 0.048	0 to 2
1	"	"	Test hole 1	0.005 to 0.040	--
1	"	"	Test hole 2	0.008 to 0.020	--
1	"	"	Test hole 3	0.001 to 0.002	--
1	"	"	Test hole 4	Under slight suction	--
2	5/89***	Fan on high	Suction pipe	1.42	80
2	"	"	Test hole 1	0.409	--
2	"	"	Test hole 2	0.385	--
2	"	"	Test hole 3	0.345	--
2	"	"	Test hole 4	0.180	--
2	"	"	Test hole 5	0.160	--

* Suctions and flows were highly dependent on outside wind speed. Weather 65 °F, slight breeze.

** Numbers refer to sub-slab test hole locations (see Figure 032-1).

*** Heating system on.

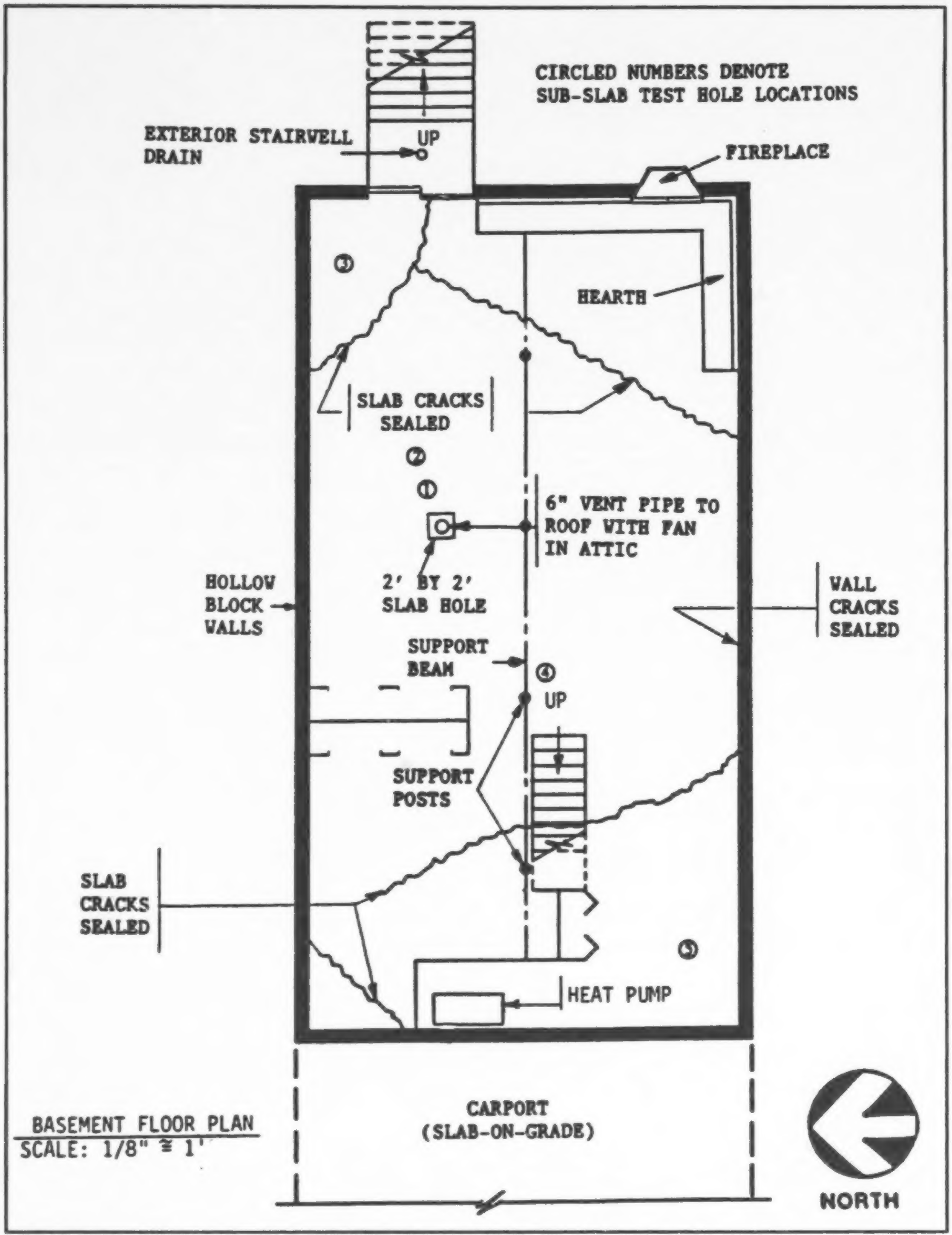

CIRCLED NUMBERS DENOTE
SUB-SLAB TEST HOLE LOCATIONS
EXTERIOR STAIRWELL DRAIN
UP
FIREPLACE
③
HEARTH
SLAB CRACKS SEALED
②
①
6" VENT PIPE TO ROOF WITH FAN IN ATTIC
2' BY 2' SLAB HOLE
HOLLOW BLOCK WALLS
WALL CRACKS SEALED
SUPPORT BEAM
④
UP
SUPPORT POSTS
SLAB CRACKS SEALED
⑤
HEAT PUMP
CARPORT
(SLAB-ON-GRADE)
BASEMENT FLOOR PLAN
SCALE: 1/8" ≅ 1'
NORTH

Figure 032-1. Basement floor plan for House 032

HOUSE 041

Basement Measurements	
Pre-mitigation Radon Levels	22.7-298 pCi/L
Stage 1 Post-mitigation Radon Levels	0.4-1.6 pCi/L

DESCRIPTION

This house is a four-level split, with a first level basement, a second level slab-on-grade living room, and an additional level above each of these two. It has poured concrete foundation walls. There is an adjoining slab-on-grade carport and a walkway. This house was built in 1981, has brick veneer and aluminum siding, and is located in a hilly rural area a few miles south of Mt. Airy, MD. There is forced-air electric heating and a living room fireplace (see Figure 041-1). The house is served by a private well.

The unfinished basement has poured concrete walls and a 4-foot stem wall between the basement and second level. There are no basement wall cracks, and the south basement wall is penetrated by the well water pipe. The basement slab is painted and has no cracks. This slab has an A/C condensate floor drain, and is penetrated by two support posts. The living room slab-on-grade is poured inside the exterior foundation walls but over the top of the stem wall. Both slabs have four inches of aggregate and a plastic vapor barrier underneath. The living room is finished with carpeting, paneling, and drywall; therefore, the floor/wall joint is not easily accessible. An exterior drain tile system around the foundation was specified in the construction plans for the house, but could not be verified. There is no sump.

ACTION - HOUSE 041

Stage 1

Due to the very high indoor radon concentrations (298 pCi/L in the basement and 222 pCi/L in the living room as measured with a Pylon), a passive system probably would not reduce the levels to below 4 pCi/L, despite the good sub-slab aggregate. Therefore, an active sub-slab depressurization system was installed, including two suction points through the basement slab and two through the stem wall under the adjoining slab on grade.

In January 1988, two 4-1/2 inch diameter access holes were drilled through the basement slab (approximately two feet from the stem wall); two additional 4-1/2 inch diameter access holes were drilled horizontally through the stem wall beneath the adjoining slab on grade. (The horizontal stem wall penetrations are as shown earlier in Figure 011-2.) The access holes were made to draw suction beneath the slab-on-grade and basement slab. Five gallons of sub-slab material was removed from each hole, and 4-inch PVC suction pipe was inserted into each of the holes. Screens were placed on the end of the suction pipes installed in the stem wall, to prevent clogging. Dampers were installed inside the four pipes to allow the flows to be balanced as desired. The four pipes were attached to a single 4-inch diameter manifold pipe. The manifold was in turn connected to another 4-inch pipe that exited the basement through the south wall band joist. This 4-inch pipe was extended up outside the house, penetrating the roof eave, and was boxed in with aluminum siding for appearance. A Kanalflakt plastic in-line duct fan (270 cfm) was attached to the top of this stack, placed inside a box enclosure on the roof and topped with a rain hat. A fan control panel was installed in the basement that contains a power switch, an on/off light to indicate suction in the vent pipe, and a rheostat to adjust the fan speed. The fan speed was set on high.

The basement floor/wall joint was ground out and sealed with flowable urethane caulk. The slab-on-grade floor/wall joint could not be ground out and sealed, because this area was inaccessible due to finishing material. A poorly-finished slab area under the basement stairs was sealed with flowable urethane. Also, the basement floor drain and the crack between the second level slab and the stem wall were sealed.

Pylon measurements were performed one week after the system was installed. With the fan off, the basement radon level was 22.7 pCi/L; with the fan on high, the level decreased to 0.6 pCi/L. Also, one of the two sub-slab vent pipes measured 251 pCi/L radon. Alpha-track detectors were deployed from February 1988 to May 1988 with the fan on high. The average basement radon level was 1.4 pCi/L and the living room was 1.1 pCi/L, demonstrating that the system was very effective.

During installation in January 1988, flow rates in the four suction pipes with the fan on high were balanced to within 4 cubic feet per minute (cfm) by adjusting the dampers. The two wall pipe flow rates were both 31 cfm and the two basement slab pipes were 35 cfm and 39 cfm. In April 1988, after the system had reached a state of equilibrium with the house and surrounding soil, flow rate tests with the fan on high were repeated. The wall pipe flow rates were 51 cfm and 54 cfm, and the slab pipes were both 24 cfm. This indicated that the wall pipe flow rates had increased, while the basement slab pipe flow rates had decreased. Also, the overall system flow rate increased from 136 cfm to 153 cfm, probably due to an increase in soil permeability. An increase in soil permeability could have been caused by the sub-slab depressurization system, since the flow of soil gas through the sub-slab area may have enhanced the removal of excess ground moisture.

In April 1988, the rate of soil gas movement under the two slabs was determined by injecting freon gas into two sub-slab test holes and testing for freon in the sub-slab depressurization pipes. Freon injected into a basement slab test hole was detected in the south basement slab vent pipe approximately 20 feet away within one minute. Also, freon injected into a slab-on-grade test hole was detected in the north wall vent pipe approximately 30 feet away in 3-1/2 minutes. Both tests demonstrated that the depressurization system was rapidly removing sub-slab soil gas from under the basement slab and the slab on grade.

Suction was detected with the fan on both high and low in three sub-slab test holes (see Figure 041-1). Because there was good pressure field extension under the two slabs and adequate suction and flow rates in the four pipes with the fan on low, the fan was reset to low.

Alpha-track detectors with the fan on low averaged 1.2 pCi/L in the living room and 1.4 pCi/L in the basement from May 1988 to August 1988. This indicated that the system was successful with the fan on low during warm weather.

In August 1988, the fan speed was returned to high to provide maximum sub-slab suction. Alpha-track detectors were deployed from January 1989 to April 1989 with the fan speed on high. The basement and living room radon levels were both 0.6 pCi/L.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 041

Gamma radiation levels measured in June 1987 were 8 uR/hr in both the basement and living room. Smoke tests made in June 1987 demonstrated that the floor/wall joint and the slab-on-grade bathroom were radon entry routes.

REMEDIATION SYSTEM - HOUSE 041

Stage	Installation Date	System Description
1	1/88	Active two-point slab-on-grade depressurization, active two-point basement sub-slab depressurization, and radon gas entry route sealing.

TEST DATA - HOUSE 041

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
--	11/87	45	Pre-mitigation	Living rm (SOG)	222	161-337
--	"	"	"	Basement	298	225-381
1	1/88	22	Fan off	Living rm	24.5	4-42
1	"	45	"	Basement	22.7	17-30
1	"	"	Fan on high	"	0.6	0-2

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Condition	Location	Reported Rn for each Detector (pCi/L)
1	2/5/88-5/4/88	Fan on high	Living room (SOG)	0.9, 1.2
1	"	"	Basement	1.3, 1.4
1	5/4/88-8/9/88	Fan on low	Living room	0.9, 1.4
1	"	"	Basement	1.1, 1.6
1	1/6/89-4/13/89	Fan on high	Living room	0.5, 0.6
1	"	"	Basement	0.4, 0.7

PYLON GRAB SAMPLES - HOUSE 041

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	6/87	Pre-mitigation	Living room (SOG)	50	0.18
--	"	"	Basement	89	0.31
1	4/88	Fan on low	Basement	0.4	--
1	"	"	Sub-slab vent pipe	251	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
3/87	Pre-mitigation	Living room (SOG)	231.6	Owner reported
"	"	Basement	365.2	"
8/87	Pre-mitigation	Basement	15.0, 15.3	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Fan Speed	Location*	Suction (inches H_2O)	Flow Rate (cfm)
1	1/88	High	South wall vent pipe	--	31
1	"	"	North wall vent pipe	--	31
1	"	"	South slab vent pipe	--	39
1	"	"	North slab vent pipe	--	35
1	4/88	High	South wall vent pipe	0.237	54
1	"	Low	"	0.111	34
1	"	High	North wall vent pipe	0.137	51
1	"	Low	"	0.062	33
1	"	High	South slab vent pipe	0.150	24
1	"	Low	"	0.073	14
1	"	High	North slab vent pipe	0.242	24
1	"	Low	"	0.103	14
1	"	High	Test hole 1	0.011	--
1	"	Low	Test hole 1	0.005	--
1	"	High	Test hole 2	0.036	--
1	"	Low	Test hole 2	0.017	--
1	"	High	Test hole 3	0.075	--
1	"	Low	Test hole 3	0.038	--

* Numbers refer to sub-slab test hole locations (see Figure 041-1).

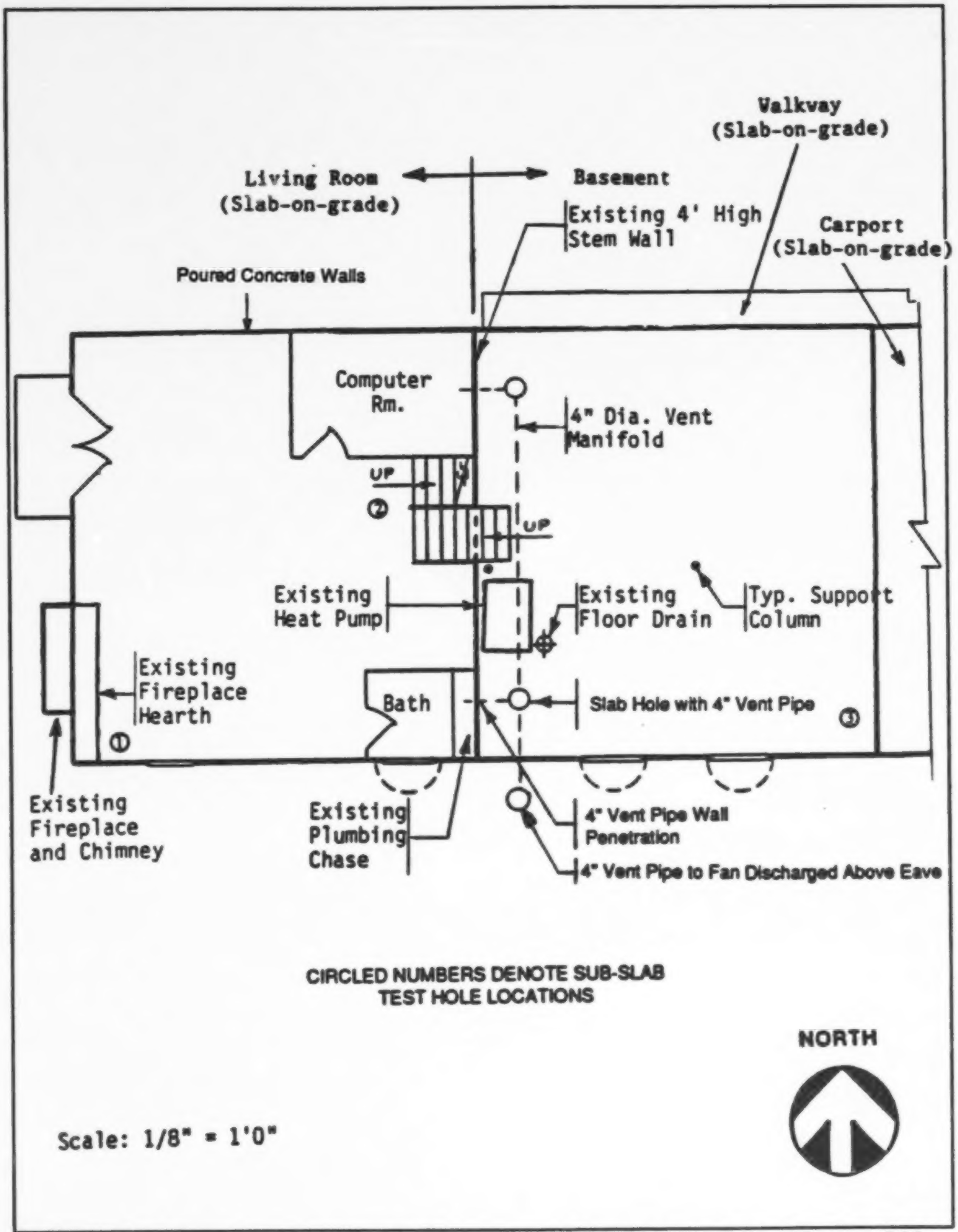

Walkway
(Slab-on-grade)
Living Room
(Slab-on-grade)
Basement
Existing 4' High
Stem Wall
Carport
(Slab-on-grade)
Poured Concrete Walls
Computer
Rm.
4" Dia. Vent
Manifold
UP
②
UP
Existing
Heat Pump
Existing
Floor Drain
Typ. Support
Column
Existing
Fireplace
Hearth
Bath
Slab Hole with 4" Vent Pipe
③
①
Existing
Fireplace
and Chimney
Existing
Plumbing
Chase
4" Vent Pipe Wall
Penetration
4" Vent Pipe to Fan Discharged Above Eave
CIRCLED NUMBERS DENOTE SUB-SLAB
TEST HOLE LOCATIONS
NORTH
Scale: 1/8" = 1'0"

Figure 041-1. Basement and slab-on-grade floor plan, House 041

HOUSE 047

Basement Measurements	
Pre-mitigation Radon Levels	7.8-11.9 pCi/L
Stage 1 Post-mitigation Radon Levels	1.3-3.2 pCi/L

DESCRIPTION

This two-story house has an unfinished basement with an adjoining crawl space. There is also an adjoining slab-on-grade garage, and a patio. The foundation walls are poured concrete. The house was built in 1981, has aluminum siding, and is located on top of a ridge in a rural area several miles northeast of Mt. Airy, MD. The house has forced-air oil heating and a first floor wood stove (see Figure 047-1). The house is served by a private well.

The basement has 8-inch thick poured concrete walls textured with brickface. The east basement wall is penetrated by oil and well water pipes, and the west wall is penetrated by a 4-inch sewer line. The south basement wall is partially a stem wall, with a frame wall on top separating the basement from the small crawl space (crawl-space dimensions 12 by 24 ft). The frame wall contains a hinged crawl space access door that is not sealed. The wall ends about 2 inches below the subflooring above, further enhancing communication of air between the crawl space and the basement. The basement slab has many hairline cracks and crushed stone underneath. There is one support post that penetrates the slab and two that rest on top. An interior drain tile and an outside basement stairwell drain empty into the basement sump. The basement has two windows and one outside door. The crawl space contains soil and gravel, and has a plastic vapor barrier that is torn. A warm air supply duct from the central furnace penetrates the frame wall between the basement and crawl space, and traverses the crawl space. Also, the furnace exhaust flue penetrates the wall and runs the length of the crawl space, tying into the chimney. There are significant openings in the frame wall around the ducts where they penetrate.

ACTION - HOUSE 047

Stage 1

Pre-mitigation continuous Pylon measurements over a two-day period found 6.5 pCi/L in the basement and 28.5 pCi/L in the crawl space, indicating that the crawl space is an important radon source. Grab sampling with the Pylon measured 206 pCi/L in the sump, 370 pCi/L in a wall penetration, and 130 pCi/L in a slab crack, indicating that radon is also coming in through openings in the basement slab. Based on these data and the relatively low basement radon level, the remediation system chosen was passive sub-liner depressurization in the crawl space, utilizing the furnace flue as the passive stack in an effort to take advantage of the suction created by the flow of the hot combustion gases up the flue. Efforts in the basement were limited to closing entry routes: sealing the sump, the pipe penetrations, and the slab cracks.

In November 1987, a straight section of rigid, 4-inch diameter perforated piping was laid on the floor of the crawl space, in the center along the long dimension of the crawl (see Figure 047-2). Since the crawl space was only 12 ft wide, no part of the crawl space floor was more than 6 ft from the pipe. The end of the pipe closest to the basement was capped. The other end, on the far end of the crawl space, was elbowed up, and attached to a length of sheet metal piping that was inserted into the metal furnace flue. The existing furnace flue is attached to the chimney that extends up the exterior of the south wall to the roof. The furnace flue was rusted and required repair. The crawl space was then covered with Mirifi fabric to provide structural support, and a heavy-duty plastic membrane (Super Sampson 400) was placed on top of the fabric. These two materials were sealed against the foundation walls using a furring strip and a continuous bead of silicone caulk. They were also sealed around the metal pipe connecting to the furnace flue. Because the crawl space was relatively small, it was possible to cover the floor with a single sheet of the plastic, thus avoiding seams between sheets.

No effort was made to better isolate the crawl space from the basement. The openings through the separating frame wall were so extensive that effective isolation would have been impossible without replacing the entire wall.

All interior slab cracks in the basement were ground out and sealed with flowable urethane caulk. The floor/wall joint was not sealed; however, this action would have been taken had the basement radon level remained elevated. The water pipe penetration through the wall was sealed with expandable foam. A plastic cover with a wooden base was placed over the sump and sealed to the slab. The exterior stairwell drain was trapped in the event that the sump later required active depressurization.

Radon levels were measured using Pylon detectors in December 1987. The basement was 2.5 pCi/L and the crawl space was 1.6 pCi/L. Winter-quarter alpha-track detectors deployed from December 1987 to March 1988 measured levels of 1.6 pCi/L in the living room (above the crawl space), 2.9 pCi/L in the basement, and 1.6 pCi/L in the crawl space. These data showed that the passive system was working well.

Post-mitigation Pylon grab samples measured radon levels of 81 pCi/L in the crawl space vent pipe and 181 pCi/L in the sump pump discharge pipe; therefore, high radon levels were being removed by the two passive depressurization systems. The floor/wall joint was measured to be 3.9 pCi/L. This indicated that the joint was not much of a radon source, and sealing it probably would not have a large effect on the already low radon levels.

One major concern in using the furnace flue as the passive stack is that the mitigation system might impact the natural draft in the flue, potentially permitting carbon monoxide to enter the basement. In March 1988, the carbon monoxide in the furnace exhaust was measured to be 10 ppm with the furnace on and less than 3 ppm with the furnace off. Also, the basement carbon monoxide level was less than 3 ppm. By comparison, the OSHA limit is 50 ppm. Thus, the system did not appear to be causing a problem.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 047

The gamma radiation level was measured to be 5 to 7 uR/hr in July 1987. Smoke tests conducted in July 1987 indicated that air was circulating in both directions through the crawl space access way. In July 1987, freon gas communication tests were made by injecting freon into the sealed sump located in the northeast basement corner. Freon was detected after two minutes in a sub-slab test hole drilled in the southwest basement approximately 35 feet away, indicating good sub-slab communication.

REMEDIATION SYSTEM - HOUSE 047

Stage	Installation Date	System Description
1	11/87	Passive sub-liner depressurization in the crawl space using the furnace flue as a stack; entry route sealing in the basement.

TEST DATA - HOUSE 047

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
--	10/87	42	Pre-mitigation	Basement	6.5	4-12
--	"	"	"	Crawl sp.	28.5	19-41
1	12/87	39	Passive on	Basement	2.5	1- 4
1	"	"	"	Crawl space	1.6	0- 2
1	6/88	44	Passive off	Basement	2.6	0.8-5.2
1	"	41	Passive on	"	2.1	0.7-4.1
1	"	43	Passive off	Crawl sp.	3.4	0.7-9.7
1	"	38	Passive on	"	2.2	0.4-4.6

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	12/11/87-3/7/88	Living room (above crawl sp.)	1.4, 1.7
1	"	Basement	2.6, 3.2
1	"	Crawl space	1.0, 2.1
1	3/7/88-6/17/88	Living room	0.8, 1.4
1	"	Basement	1.5, 1.9
1	"	Crawl space	1.5, 2.0
1	6/17/88-9/29/88	Living room	0.5, 0.8
1	"	Basement	1.3, 1.3
1	"	Crawl space	1.6. 2.0
1	9/29/88-1/6/89	Living room	1.5, 1.6
1	"	Basement	2.4, 3.0
1	"	Crawl space	2.2, 2.8
1	1/6/89-4/13/89	Living room	0.7, 1.3
1	"	Basement	2.3, 2.4
1	"	Crawl space	1.7, 1.9

PYLON GRAB SAMPLES - HOUSE 047

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	6/87	Pre-mitigation	Living room (above crawl space)	1	0.008
--	"	"	Basement	18	0.084
--	"	"	Water pipe penetration	370	--
--	"	"	Sump	62	--
--	7/87	Pre-mitigation	Basement	8-14	0.024
--	"	"	Crawl space access	11	--
--	"	"	Wall opening	34	--
--	"	"	Sump	206	--
--	"	"	Slab crack	130	--
1	3/88	Furnace off	Basement	3.1	--
1	"	"	Crawl space	1.2	--
1	"	Furnace on	SLD piping	81.0	--
1	"	Furnace off	Sump pump discharge pipe	181	--
1	"	"	Floor/wall joint	3.9	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
<3/87	Pre-mitigation	Basement	11.1	Owner reported
8/87	Pre-mitigation	Basement	3.2, 14.3	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Test Condition	Location**	Suction (inches H_2O)	Flow Rate (cfm)
1	3/88	Furnace off	Furnace flue	--	8
1	"	Furnace on	"	--	32
1	"	Furnace off	SLD piping	--	9 to 26
1	"	Furnace on	"	--	13 to 23

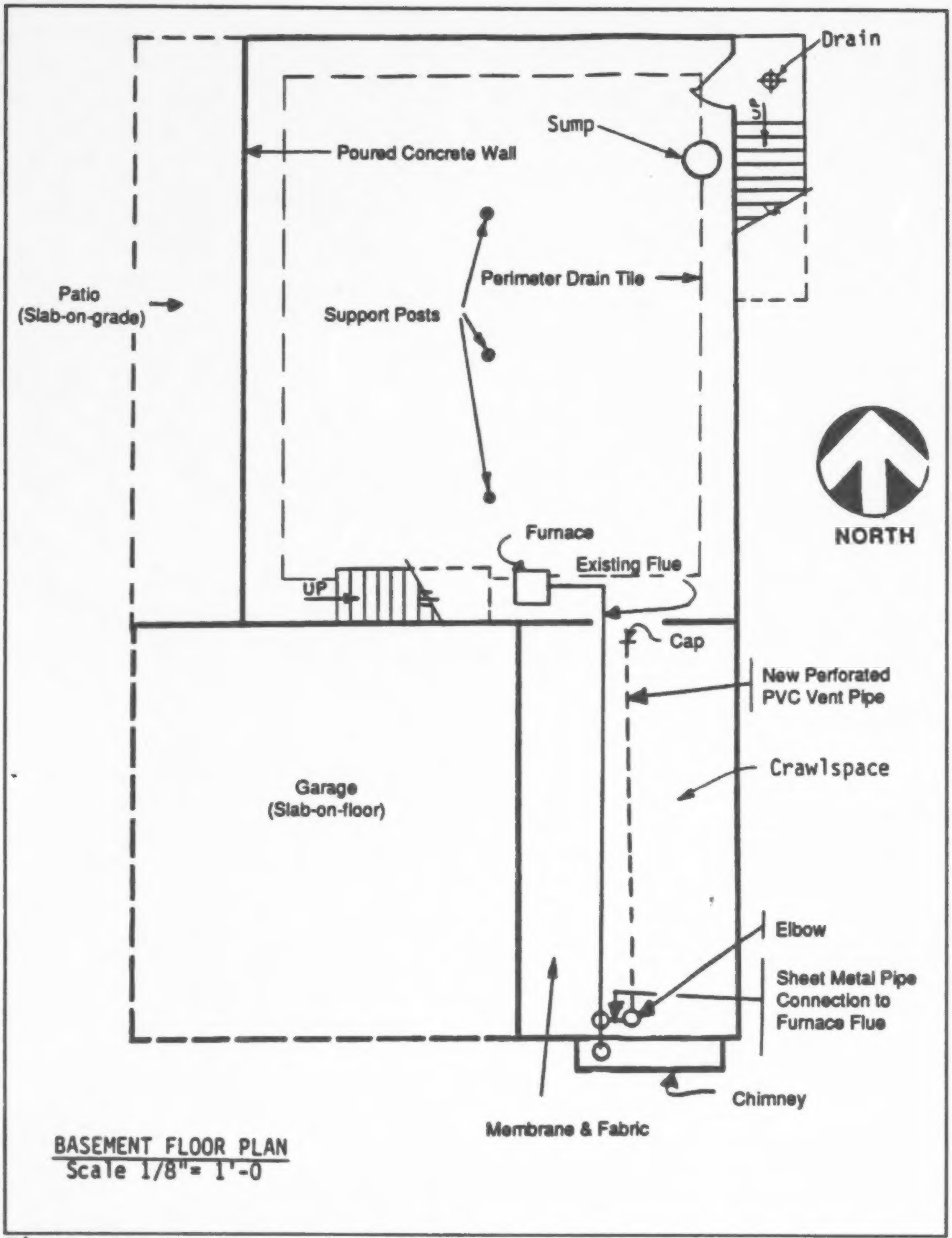

Drain
UP
Sump
Poured Concrete Wall
Perimeter Drain Tile
Patio
(Slab-on-grade)
Support Posts
NORTH
Furnace
Existing Flue
UP
Cap
New Perforated
PVC Vent Pipe
Crawlspace
Garage
(Slab-on-floor)
Elbow
Sheet Metal Pipe
Connection to
Furnace Flue
Chimney
Membrane & Fabric
BASEMENT FLOOR PLAN
Scale 1/8"= 1'-0

Figure 047-1. Basement floor plan for House 047

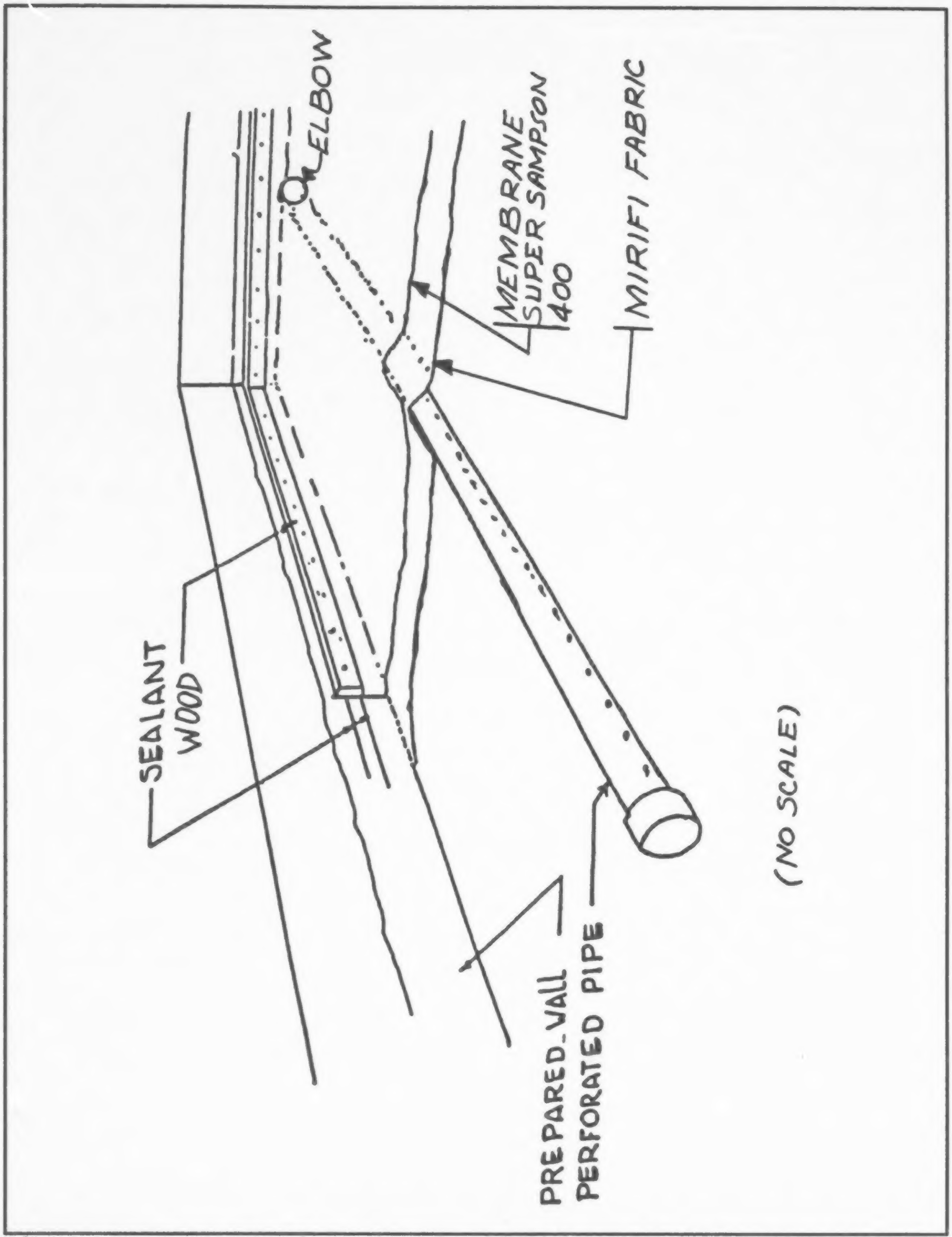

SEALANT
WOOD
ELBOW
PREPARED WALL
PERFORATED PIPE
MEMBRANE
SUPER SAMPSON
400
MIRIFI FABRIC
(NO SCALE)

Figure 047-2. Sub-liner depressurization system in House 047

HOUSE 054

Basement Measurements	
Pre-mitigation Radon Levels	9.9-33.4 pCi/L
Stage 1 Post-mitigation Radon Levels	5.9-13.5 pCi/L
Stage 2 Post-mitigation Radon Levels	1.6-10.8 pCi/L

DESCRIPTION

This is a split-level house with a first level finished basement, an adjoining crawl space, and another level above the basement. The basement and crawl space have hollow block foundation walls. There is an attached slab-on-grade patio, breezeway, and garage. This house was built in 1971 and has aluminum siding and brick veneer. It is located in a hilly area in a subdivision several miles north of Mt. Airy, MD. There is a gas-fired forced air furnace, and a wood stove in the basement. The house is served by a private well. See Figure 054-1.

The basement concrete block walls are finished with paneling and are penetrated by the well water pipe, the gas furnace flue, and the wood stove flue. The north and south basement walls are approximately 4 feet below grade, and the west wall is above grade. Most of the basement has carpeting and tile, and cracks are present in the unfinished utility rooms. The slab is penetrated by a sewer pipe. There is no sump or drain tile. There is a plywood crawl space access door. The crawl space is completely below grade. There is four feet of headroom in the crawl space. The perimeter block foundation walls visible in the crawl space have solid cap blocks. The crawl space floor is located approximately 1 foot below the level of the basement slab, and has 4 inches of crushed stone over the soil. The north crawl space wall has a single foundation wall vent, located in a 10-inch deep well.

ACTION - HOUSE 054

Stage 1

The basement and the crawl space had only moderately elevated radon concentrations (12.4 and 8.7 pCi/L, respectively), as measured with a Pylon during December 1987. Communication under the basement slab appeared to be good, according to pre-mitigation freon gas communication tests). It was decided to install a passive sub-slab depressurization system in the basement, and to add a second foundation vent in the crawl space to increase natural crawl space ventilation.

In March 1988, a 6-1/2 inch diameter hole was drilled through the slab on the east side of the basement next to the interior footer between the basement and the crawl space. Ten gallons of mostly large stones and dirt were excavated. A 1-inch thick layer of gravel aggregate was present below the slab. A 6-inch diameter PVC suction pipe was placed through the hole. The passive stack extended through a second level closet to the attic. The stack was installed straight up from the basement to the attic with no bends in the pipe. The suction pipe in the basement was boxed in with drywall. A wind turbine attached to the stack, mounted on the roof. The slab cracks in the unfinished part of the basement were ground out and sealed with flowable urethane. A new crawl space door was installed that provided a tight seal, to better isolate the crawl space from the basement. A second crawl space foundation vent was created by drilling a series of 1-inch diameter holes through the band joist and exterior finish, on the wall opposite the existing vent; these holes were covered on the outside with a grille.

In March 1988, post-mitigation Pylon measurements were made to determine radon concentrations. The radon level in the crawl space was 16.3 pCi/L, and in the basement was 13.5 pCi/L. Both values were actually higher than pre-mitigation Pylon levels measured in the previous December, and demonstrated that increasing the crawl space ventilation rate and passively depressurizing the basement slab had not been effective.

In March 1988, suction and flow rate measurements were taken on a 40 °F, breezy day with the wind turbine spinning well. Suction inside the suction pipe relative to the basement ranged from 0.050 to 0.090 inches of water, and the flow rate in the vent pipe was 1 cubic foot per minute. These suction and flow rate values were low, but consistent with what would be expected with a passive depressurization system. Sub-slab suction field extension measurements indicated that the sub-slab area 5 feet from the vent pipe was at the same pressure as the basement. Two other sub-slab test holes, located 12 feet and 22 feet from the suction pipe, were both pressurized to 0.007 inches of water. According to these data, most of the sub-slab was not under suction, indicating why the radon levels had not been lowered by the passive system. The lack of sub-slab suction was partly due to low vent pipe suction created by the wind turbine. As it was later determined, it was also due to poor/uneven sub-slab communication, as suggested by the relatively thin layer of sub-slab aggregate seen through the hole when the passive pipe was installed. Pre-mitigation freon gas communication tests had suggested good sub-slab communication on the north side of the basement; however, perhaps in part due to the low suction drawn by the wind turbine, this area of the sub-slab was not being depressurized.)

On the day of that the suction measurements were made, freon gas was injected into the sub-slab test hole located 5 feet from the suction pipe. It was not detected in the suction pipe after 20 minutes, and further demonstrated the poor performance of the passive depressurization system. However, a Pylon grab sample taken in the vent pipe was 891 pCi/L, indicating that the depressurization system was removing some radon from below the basement slab; but this was probably from the area close to the suction pipe.

In June 1988, additional two-day Pylon measurements were made. The crawl-space radon level was 1.8 pCi/L with the passive system off and 1.7 pCi/L with the system on. The basement was 9.9 pCi/L with the passive system off and 5.9 pCi/L with the system on. Since the crawl space level was very low with the passive system off, no conclusion could be drawn about the low level when the passive system was turned back on. The basement radon data suggested that the passive system was providing a moderate reduction in the basement radon levels. Considering that the system was shown to be ineffective by March 1988 Pylon tests, as indicated previously, the decrease in the basement radon level that the passive system appeared to be providing in June suggests that, as might be expected, the performance of the passive system can vary over time, as the driving force for radon entry and the passively-generated suction change.

Based on the poor performance of the passive system, additional passive approaches, such as installing a second passive sub-slab depressurization system in the unfinished part of the basement, probably would not have been effective.

Stage 2

In July 1988, the passive depressurization system in the basement was activated by installing an in-line duct fan inside the attic. Wiring that had been pre-installed during Stage 1 was used, and the wind turbine was left in place to reduce installation costs.

Pylon tests were performed in July 1988 to measure radon levels. The crawl space was 6.5 pCi/L with the fan off and was 1.2 pCi/L with the fan on. The basement was 14.8 pCi/L with the fan off and 2.1 pCi/L with the fan on. These data suggested that the active vent system had significantly reduced the radon levels. However, alpha-track detectors deployed from July 1988 to November 1988 measured 2.0 pCi/L in the crawl space and 6.1 pCi/L in the basement. These alpha-track data provided a better indication of the average radon levels than did the two-day Pylon measurements. The data also indicated that the active system was unsuccessful in consistently reducing the basement levels to below EPA's recommended radon action level of 4 pCi/L.

In January 1989, additional Pylon tests were conducted. With the fan off, the basement radon level was 33.4 pCi/L and decreased to 16.0 pCi/L when the fan was turned on. No data were recorded for the crawl space during this period. Pylon tests were repeated a few weeks later to test the basement and crawl space. With the fan off, the crawl space radon level was 11.7 pCi/L and the basement was 21.0 pCi/L. After the fan was turned on, the crawl space level decreased to 6.6 pCi/L and the basement decreased to 8.8 pCi/L. These data indicated that the crawl space and basement were both still above 4 pCi/L.

Winter-quarter alpha-track detectors in place from November 1988 to February 1989 measured 4.1 pCi/L in the crawl space and 9.9 pCi/L in the basement. While the active system had lowered the radon levels from pre-mitigation levels (8.7 pCi/L in the crawl space and 12.4 pCi/L in the basement), additional mitigation steps would be required.

Subsequent testing verified that sub-slab communication was poor and uneven. A second active SSD system was installed in the unfinished portion of the basement slab, achieving levels <4 pCi/L.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 054

In October 1987, the gamma radiation level in the basement was 8 uR/hr. Freon gas communication tests were conducted by injecting freon gas into a sub-slab test hole located in the northeast basement corner. The gas was detected in a second test hole located 15 feet away in 1-1/2 minutes, indicating good sub-slab communication on the north part of the slab.

REMEDIATION SYSTEM - HOUSE 054

Stage	Installation Date	System Description
1	3/88	Passive sub-slab depressurization and increased natural crawl space ventilation.
2	7/88	Active sub-slab depressurization.

TEST DATA - HOUSE 054

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
-	12/87	42	Pre-mitigation	Crawl sp.	8.7	3-21
-	"	"	"	Basement	12.4	8-20
1	3/88	85	Passive on	Crawl sp.	16.3	6-42
1	"	"	"	Basement	13.5	3-25
1	6/88	39	Passive off	Crawl sp.	1.8	0.7-2.7
1	"	37	Passive on	"	1.7	0.4-3.1
1	"	41	Passive off	Basement	9.9	2.0-23.7
1	"	39	Passive on	"	5.9	0.6-18.2
2	7/88	47	Fan off	Crawl sp.	6.5	0.5-44.8
2	"	41	Fan on	"	1.2	0.5-3.1
2	"	42	Fan off	Basement	14.8	2.6-48.5
2	"	41	Fan on	"	2.1	0.4-6.2
2	1/89	45	Fan off	Basement	33.4	5.6-61.3
2	"	46	Fan on	"	16.0	5.9-23.8
2	1/89	41	Fan off	Crawl sp.	11.7	4.5-9.1
2	"	44	Fan on	"	6.6	0.9-13.7
2	"	46	Fan off	Basement	21.0	11.2-25.7
2	"	42	Fan on	"	8.8	1.8-12.0

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
2	7/26/88-11/17/88	Crawl space	1.6, 2.4
2	"	Basement	5.7, 6.5
2	11/17/88-2/16/89	Crawl space	3.8, 4.4
2	"	Basement	8.9, 10.8

PYLON GRAB SAMPLES - HOUSE 054

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
-	6/9/87	Pre-mitigation	Basement	10	0.049
-	"	"	Crawl space	6	0.029
-	"	"	Crawl space block wall	13	-
-	10/8/87	Pre-mitigation	Basement	8	0.020
-	"	"	Below slab	2195	-
-	"	"	Crawl space	4	0.015
-	"	"	Living room (above slab-on-grade)	-	0.026
1	3/23/88	Passive on	Basement	14	-
1	"	"	Crawl space	44	-
1	"	"	Suction pipe	891	-

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
4/86	Pre-mitigation	Master bedroom	11	Owner reported
"	"	Bedroom	12	"
"	"	Nursery	13	"
"	"	Living room	14	"
"	"	Kitchen	23	"
"	"	Basement	20	"
"	"	Crawl space	35	"
8/87	Pre-mitigation	Uncertain	10.2, 12.2	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Location*	Suction** (inches H_2O)	Flow Rate (cfm)
1	3/23/88	Vent pipe	0.050 to 0.090	1
1	"	Test hole 1	0.000	-
1	"	Test hole 2	-0.007	-
1	"	Test hole 3	-0.007	-

* Numbers refer to sub-slab test hole locations (see Figure 054-1). Weather 40 °F, breezy, wind turbine spinning well.

** Negative suction indicates area is pressurized relative to house.

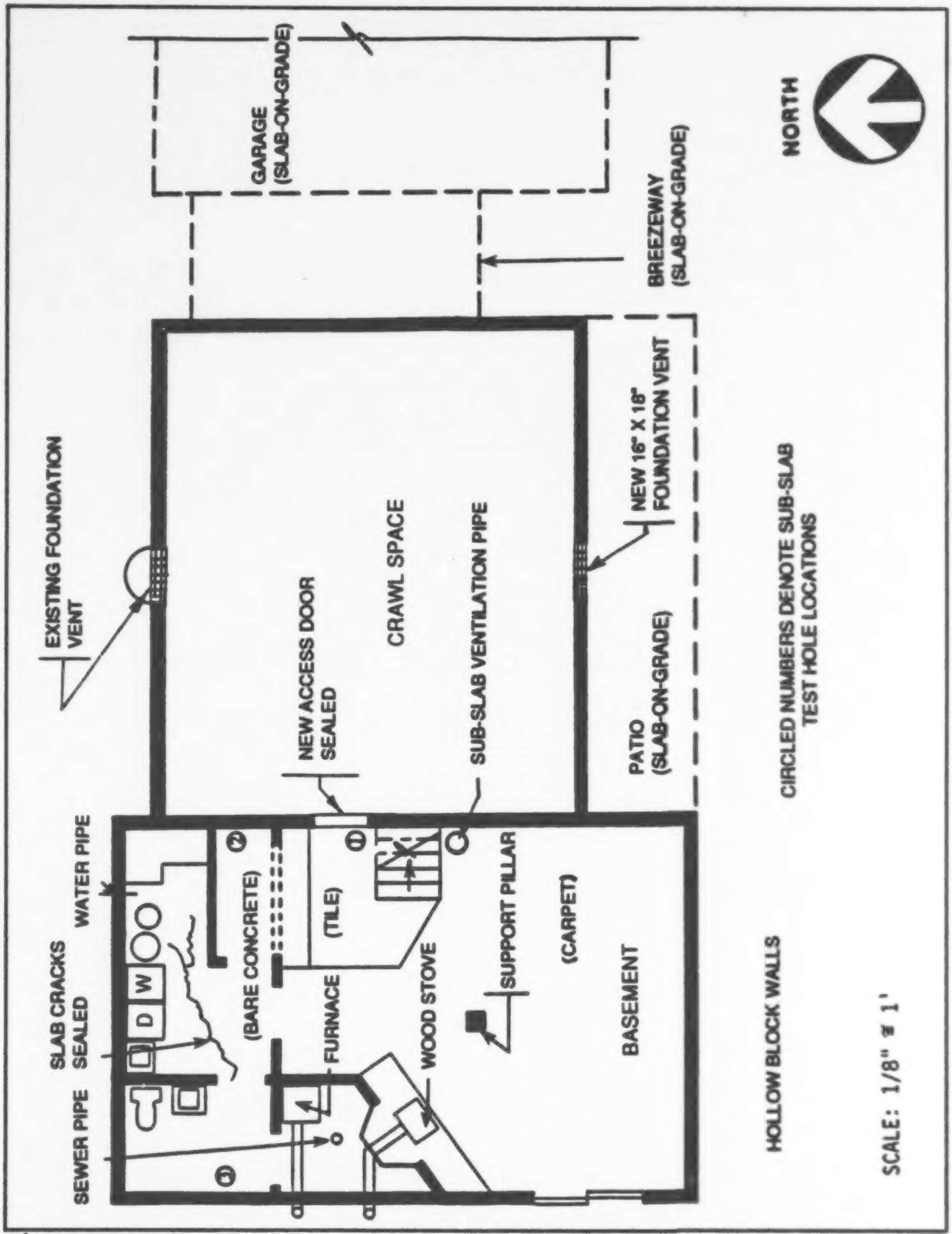

GARAGE (SLAB-ON-GRADE)
BREEZEWAY (SLAB-ON-GRADE)
NORTH
EXISTING FOUNDATION VENT
NEW 16" X 18" FOUNDATION VENT
CRAWL SPACE
NEW ACCESS DOOR SEALED
SUB-SLAB VENTILATION PIPE
PATIO (SLAB-ON-GRADE)
CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
SEWER PIPE
SLAB CRACKS SEALED
WATER PIPE
D
W
(BARE CONCRETE)
(TILE)
FURNACE
WOOD STOVE
SUPPORT PILLAR
(CARPET)
BASEMENT
①
②
③
HOLLOW BLOCK WALLS
SCALE: 1/8" = 1'

Figure 054-1. Basement and crawl space floor plan, House 054

HOUSE 061

Basement Measurements

Pre-mitigation Radon Levels	9.1-14.5 pCi/L
Stage 1 Post-mitigation Radon Levels	4.4-7.0 pCi/L
Stage 2 Post-mitigation Radon Levels	0.4 pCi/L

DESCRIPTION

This one-story house has a finished basement with hollow concrete block foundation walls. There is an attached slab-on-grade carport and a patio. The house was built in 1974 on hilly land in a subdivision a few miles north of Frederick, MD. The house uses forced-air electric heat, and there is a basement fireplace that is used occasionally. The house is served by a private well. See the floor plan in Figure 061-1).

The basement is located approximately one half below grade, and has seven outside windows. The four basement walls are hollow concrete block with open top voids. Sill plates rest on the top voids, and the seam between the sill plate and the wall has been caulked by the owner. The basement walls have paneling, except for the workshop and the storage room. The workshop block wall is penetrated by a well water pipe and an electric wire. The basement slab is covered with either carpet or tile in all areas, except the storage room. There are two small concrete patches and hairline cracks in the storage room slab. The slab in the laundry room is penetrated by the sewer pipe. The floor/wall joint is tight where visible. The plastic-lined sump, located in the northeast basement corner, has two 4-inch diameter perimeter drain tiles entering it. It is not known if the drain tile forms a complete loop, or if the drain tile is interior or exterior. The sump has no pump and is covered with sheets of plastic. Stone aggregate is visible in the bottom of the sump. An exterior stairwell landing pad has a floor drain which drains to the sump.

ACTION - HOUSE 061

Stage 1

Passive drain tile depressurization via the sump, together with sealing of accessible slab openings, were the mitigation techniques chosen for this house. Installed was carried out in March 1988. A plywood cover was bolted over the sump pit, resting in a lip in the slab around the sump perimeter; the channel between the plywood and the outer circumference of the lip was sealed with flowable urethane caulk. A 4-inch PVC suction pipe was inserted through the cover. The stack from this pipe was extended up through the basement, and boxed in for appearance. Once above the drop-down ceiling in the basement, the 4-inch stack was extended horizontally several feet to a point where it could rise up through the house. It was routed through a first floor bedroom closet and up to the first floor ceiling. At this level, the stack was increased in diameter to 6-inches, and was extended up to the attic. In the attic, the stack was covered with fiberglass insulation. It penetrated the roof, and was connected to a 12-inch wind-driven turbine mounted on the roof. The two small patched areas in the storage room slab were sealed.

Alpha-track detectors were deployed from August 1988 to November 1988. Average radon levels were 6.0 pCi/L in the basement workshop, 4.6 pCi/L in the basement family room, and 3.8 pCi/L in the dining room. Pylon tests were taken with the passive system both on and off in November 1988. The levels in the basement workshop were 9.2 pCi/L with the passive system off and 7.0 pCi/L with it on. The dining room levels were 7.7 pCi/L with the passive system off and 6.5 pCi/L with it on. These data indicate that only minor radon reductions were achieved with the passive depressurization system.

Stage 2

In December 1988, the passive drain tile depressurization system was activated by installing a Fantech in-line duct fan (270 cfm) in the attic. A portion of the 6-inch stack in the attic was removed to create space for the fan. Wiring that was pre-installed during Stage 1 was used. The roof-mounted wind turbine was kept in place to minimize installation costs, and was not expected to create much resistance to vent pipe air flow.

A fan control panel was installed in the basement, containing a power switch, an on/off light to indicate suction in the vent pipe, and a rheostat to adjust the fan speed.

In December 1988, radon levels were determined with the fan both off and on. Basement workshop levels were 5.9 pCi/L with the fan off and 0.4 pCi/L with it on. Dining room levels were 5.2 pCi/L with the fan off and 0.4 pCi/L with it on. Therefore, the active drain tile depressurization system had greater influence on radon levels than did the passive system.

In May 1989, suction and flow rate measurements were made. Inside the stack on the first floor, the suction relative to the first floor was 0.903 inches of water and the flow rate was 140 cfm. The suction inside the sealed sump relative to the basement was 0.128 inches of water, which indicated that there was a large pressure drop between the sump and the stack on the first floor. Sub-slab suction relative to the basement was 0.048 inches of water in a test hole 1-1/2 feet from the sump, 0.024 inches of water 12 feet from the sump, and ranged from 0.004 to 0.012 inches of water 25 feet from the sump. Therefore, the active system was depressurizing at least part of the basement sub-slab area.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 061

Gamma radiation was not detected in the basement in June 1987. Smoke tests made in June 1987 showed that soil gas was entering the basement through the sump and the two wall penetrations in the workshop. Freon gas communication tests were made in October 1987 by injecting freon into the sump and applying suction to a test hole in the workshop located approximately 30 feet away. Freon was detected in the vacuum exhaust after 2 minutes, thus indicating relatively good sub-slab communication.

REMEDIATION SYSTEM - HOUSE 061

Stage	Installation Date	System Description
1	3/88	Passive drain tile depressurization via the sump and slab patch sealing.
2	12/88	Active drain tile depressurization.

TEST DATA - HOUSE 061

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
--	12/87	47	Pre-mitigation	Basement workshop	12.3	4-20
--	2/88	46	"	Basement family rm	9.1	7-11
1	4/88	89	Passive on	Workshop	5.7	1-11
1	"	"	"	Family rm	6.9	3-10
1	11/88	43	Passive off	Workshop	9.2	3.7-14.5
1	"	47	Passive on	"	7.0	2.1-11.1
1	"	43	Passive off	Dining rm	7.7	2.2-14.4
1	"	47	Passive on	"	6.5	1.8-9.8
2	12/88	49	Fan off	Workshop	5.9	3.4-9.3
2	"	41	Fan on	"	0.4	0.2-0.7
2	"	49	Fan off	Dining rm	5.2	1.3-9.0
2	"	41	Fan on	"	0.4	0.0-0.8

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	8/2/88-11/17/88	Basement workshop	5.1, 7.0
1	"	Basement family room	4.4, 4.9
1	"	Dining room	3.8, 3.8
1,2	11/17/88-2/21/89	Basement workshop	2.3, 3.4
1,2	11/17/88-2/16/89	Basement family room	2.3, 2.4
1,2	"	Dining room	*

* Data outside QC goals.

PYLON GRAB SAMPLES - HOUSE 061

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	6/87	Pre-mitigation	Basement	22.8	0.133
--	"	"	Dining room	12.0	0.048
--	"	"	Inside sump	63.5	--
--	10/87	Pre-mitigation	Basement workshop	15.6	0.034
--	"	"	Basement family rm	12.3	0.031
--	"	"	Dining room	--	0.026
--	"	"	Inside sump	44.0	--
1	4/88	Post-mit.	Basement	7.3	--
1	"	"	Block wall in workshop	23.8	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
--	Pre-mitigation	Basement family rm	12.0	Owner reported
8/87	Pre-mitigation	Uncertain	11.4, 14.5	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Location*	Suction (inches H_2O)	Flow Rate (cfm)
1	4/88	Suction pipe	0.020**	-
1	"	Inside sealed sump	0.0 to 0.018**	-
1	"	Test hole 1	0.000**	-
2	5/89	Stack (on first floor)	0.903	140
2	"	Inside sealed sump	0.128	-
2	"	Test hole 1	0.004 to 0.012	-
2	"	Test hole 2	0.024	-
2	"	Test hole 3	0.048	-

* Numbers refer to sub-slab test hole locations (see Figure 061-1).

** Suction was dependent on outside wind speed. Weather 65 °F, slight breeze.

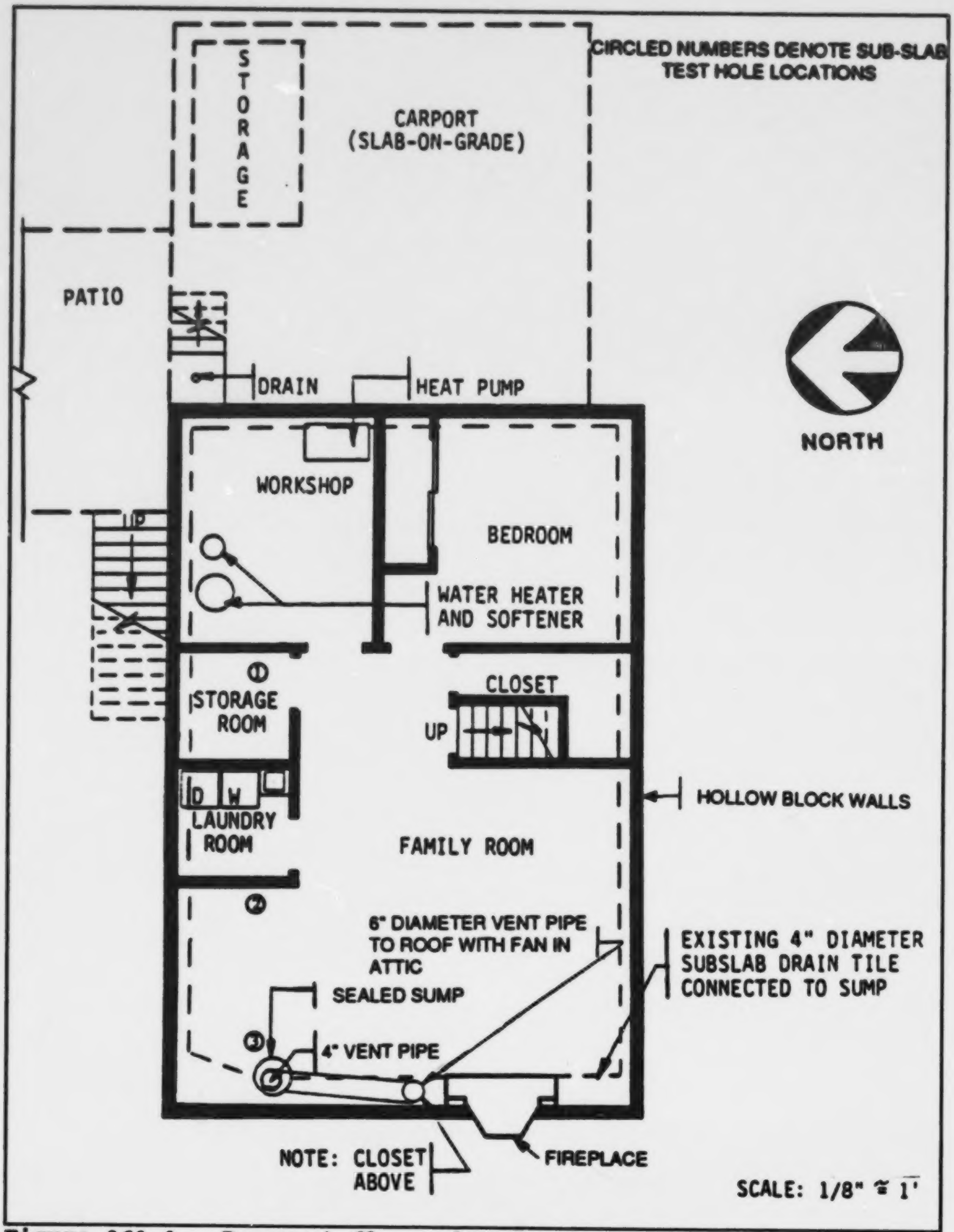

CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
STORAGE
CARPORT (SLAB-ON-GRADE)
PATIO
DRAIN
HEAT PUMP
NORTH
UP
WORKSHOP
BEDROOM
WATER HEATER AND SOFTENER
①
STORAGE ROOM
CLOSET
UP
D
W
LAUNDRY ROOM
HOLLOW BLOCK WALLS
FAMILY ROOM
②
6" DIAMETER VENT PIPE TO ROOF WITH FAN IN ATTIC
EXISTING 4" DIAMETER SUBSLAB DRAIN TILE CONNECTED TO SUMP
SEALED SUMP
③
4" VENT PIPE
NOTE: CLOSET ABOVE
FIREPLACE
SCALE: 1/8" ≅ 1'

Figure 061-1. Basement floor plan for House 061

HOUSE 069

Basement Measurements	
Pre-mitigation Radon Levels	9.4-20.0 pCi/L
Stage 1 Post-mitigation Radon Levels	3.8-7.2 pCi/L
Stage 2 Post-mitigation Radon Levels	3.4-11.3 pCi/L
Stage 3 Post-mitigation Radon Levels	0.2-1.3 pCi/L

DESCRIPTION

This two-story house has an unfinished basement and an adjoining crawl space, both with hollow block foundation walls. The house was built in 1983, has vinyl siding, and is located on the upper part of a hill in a rural area several miles east of Mt. Airy, MD. The house uses forced-air electric heating, and has a private well. See the floor plan in Figure 069-1.

The four basement walls are hollow block, with a solid cap block on top. The south basement wall is above grade and has a sliding glass door and a window. The east wall is penetrated by the sewer and the well water pipes, and the north wall has two small holes. None of the walls have cracks. The basement slab has no cracks, and is penetrated by 2 hollow support posts and a 1-inch diameter condensate drain pipe. There is no sump, but an interior perimeter drain tile is present. The homeowner reported that underneath the slab is a vapor barrier and 1/2 inch of crushed stone aggregate. The floor/wall joint is approximately 1/32 inch to 1/8 inch wide all around the perimeter. The crawl space access way is on the north basement wall. The crawl space also has block foundation walls with solid cap block. The crawl-space floor is exposed clay soil; there is plastic sheeting over the floor, but much of the soil is exposed. There are two foundation vents, one each on the east and west walls. Supply and return ducts for the forced-air heating system traverse the crawl space; but there are no water pipes.

ACTION - HOUSE 069

Stage 1

The mitigation system chosen for this house was passive sub-slab depressurization and radon gas entry route sealing in the basement, and increased natural ventilation in the crawl space. In January 1988, a 4-1/2 inch diameter hole was drilled through the slab roughly in the center of the basement; a hole was excavated under the slab at this point, with about five gallons of gravel and dirt being removed. Several inches of aggregate were visible through the hole. A 4-inch PVC suction pipe was inserted in the hole. The pipe was extended up to the basement ceiling, then directed horizontally to the north basement wall. A 6-inch stack was attached to the 4-inch pipe at this location, and the stack was extended up through the house to the attic. Fiberglass insulation was placed on the stack in the attic. The vent pipe was framed in on the first and second floors, for appearance. The stack penetrated the roof and was connected to a wind-driven turbine attached to the roof. The floor/wall joint was ground out and sealed with flowable polyurethane. Also, the holes in the north basement wall were sealed.

Two additional exterior vents (approximate dimensions 5 by 15 inches) were installed in the north crawl space wall to improve natural ventilation. A wooden door was placed on the crawl space access way and sealed with metal tape, to help isolate the crawl space from the basement. In addition, other openings in the wall between the basement and crawl space -- where forced-air ducts and a structural I-beam penetrated -- were foamed closed.

Pylon testing performed in January 1988 with the passive system operating measured radon levels of 7.2 pCi/L in the basement and 4.3 pCi/L in the living room. Pressure field extension measurements taken in March 1988, with the wind turbine spinning and with 0.03 to 0.07 in. WG suction in the pipe, indicated that there was 0.005 to 0.017 in. WG suction under the slab at two test holes within 6 feet of the suction pipe. However, positive sub-slab pressure was detected in two test holes approximately 15 feet from the pipe.

In June 1988, Pylon measurements were made simultaneously in the living room, the basement, the crawl space, and inside the north basement block wall. With the passive system operating, the radon levels were 1.7 pCi/L in the living room, 4.8 pCi/L in the basement, 5.9 pCi/L in the crawl space, and 41.6 pCi/L inside the north basement wall. In addition, a grab radon sample taken from below the slab was 910 pCi/L, and a sample from inside the suction pipe was 368 pCi/L.

Stage 2

Additional mitigation work was warranted due to the continuing elevated radon levels in the basement and crawl space. Since the Pylon data indicated that the north basement wall adjacent to the crawl space had high radon levels, it could thus be a source. Also, the pressure field extension measurements demonstrated that the passive system was influencing only part of the basement slab. Therefore, to reduce block wall radon levels and to influence more of the sub-slab, an additional passive suction point was installed through the slab, and a pipe was inserted into the voids in the block wall.

In July 1988, a 4-1/2 inch diameter hole was drilled through the slab directly below the original 6-inch passive stack immediately beside the north wall of the basement. A second 4-inch suction pipe was inserted through this hole, and connected to the stack. An interior perimeter drain tile was discovered under the slab during the drilling of this hole. Another 4-1/2 inch diameter hole was drilled horizontally into the cavities in the center of the north wall, directly above the new slab hole and approximately two feet above the floor. A 4-inch PVC pipe was inserted into the wall hole. This pipe was also connected to the original stack.

Shortly after the Stage 2 mitigation system had been installed, the homeowner remodeled the basement. The basement was sectioned off into three separate rooms by interior walls. Also, approximately 60 percent of the basement block walls were covered with paneling and plaster board.

Pylon tests made in July 1988 measured radon levels of 3.4 pCi/L in the basement and 2.7 pCi/L in the living room. However, follow-up Pylon tests in November 1988, during cooler weather, measured a basement level of 10.9 pCi/L and a living room level of 5.3 pCi/L. These elevated results were confirmed by long-term alpha-track detectors deployed from August 1988 to December 1988, which measured 10.2 pCi/L in the basement and 6.4 pCi/L in the living room.

Stage 3

As a final mitigation step, the passive sub-slab and wall depressurization system was activated in December 1988. A portion of the 6-inch stack in the attic was removed and replaced with a Fantech in-line duct fan (270 cfm). The roof-mounted wind turbine was not replaced with a rain hat, to minimize installation costs.

In the basement, a fan control panel was installed and equipped with a power switch, an on/off light to indicate suction in the vent pipe, and a rheostat to adjust the fan speed.

Pylon testing was performed in January 1989. With the fan off, the radon levels were 5.6 pCi/L in the living room and 11.6 pCi/L in the basement. After the fan was turned back on, the radon levels were 0.4 pCi/L in the living room and 0.2 pCi/L in the basement.

Stage 3 alpha-track detectors were deployed from December 1988 to March 1989. The radon level in the living room was 1.2 pCi/L and the level in the basement was 1.2 pCi/L, indicating that the active system was effective.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 069

Gamma radiation levels in the basement ranged from 8 to 9 uR/hr in June 1987. Freon gas communication tests were made under the basement slab in July 1987. Freon gas injected into a sub-slab test hole drilled in the northwest corner was detected after one minute in a second hole located near the southeast corner approximately 30 feet away. This indicated good sub-slab communication.

REMEDIATION SYSTEM - HOUSE 069

Stage	Installation Date	System Description
1	1/88	Passive sub-slab depressurization, increased crawl space ventilation, and entry route sealing.
2	7/88	Improved (two-point) passive sub-slab depressurization plus block wall depressurization.
3	12/88	Active two-point sub-slab and wall depressurization.

TEST DATA - HOUSE 069

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
-	11/87	47	Pre-mitigation	Living rm (above CS)	8.5	3-11
-	"	"	"	Basement	13.2	11-16
1	1/88	47	Passive on	Living rm	4.3	3-6
1	"	"	"	Basement	7.2	5-10
1	6/88	43	Passive off	Living rm	7.0	2.4-13.2
1	"	33	Passive on	"	1.7	0.0-3.7
1	"	44	Passive off	Basement	14.7	7.8-21.0
1	"	38	Passive on	"	4.8	1.1- 9.9
1	"	48	Passive off	Crawl sp.	1.5	0.3- 5.5
1	"	42	Passive on	"	5.9	0.1-41.6
1	"	48	Passive off	Inside north wall	14.7	0.6-138
1	"	42	Passive on	"	41.6	0.3-128
2	7/88	93	Passive on	Living rm	2.7	0.6- 5.2
2	"	"	"	Basement	3.4	1.0- 7.9
2	11/88	93	Passive on	Living rm	5.3	0.4- 9.9
2	"	"	"	Basement	10.9	2.8-26.7
3	1/89	37	Fan off	Living rm	6.8	4.4- 8.9
3	"	48	Fan on	"	0.3	0.1- 0.7
3	"	38	Fan off	Basement	9.8	6.3-16.2
3	"	4	Fan on	"	0.8	0.3- 1.7
3	"	44	Fan off	Living rm	5.6	3.5- 7.2
3	"	40	Fan on	"	0.4	0.1- 0.6
3	"	47	Fan off	Basement	11.6	5.9-17.8
3	"	42	Fan on	"	0.2	0.0- 0.5

ALPHA-TRACK DETECTOR MEASUREMENTS - HOUSE 069

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	2/5/88-5/4/88	Living room (above crawl space)	2.7, 2.8
1	"	Basement	5.2, 5.2, 5.5
1,2	5/4/88-8/2/88	Living room	2.7, 3.5
1,2	"	Basement	3.8, 4.8, 5.1
2	8/2/88-12/7/88	Living room	6.1, 6.6
2	"	Basement	8.2, 11.1, 11.3
3	12/7/88-3/15/89	Living room	1.0, 1.3
3	"	Basement	1.0, 1.2, 1.3

PYLON GRAB SAMPLES

Stage	Date	Test Condition	Location	Radon Level (pCi/L)
--	7/87	Pre-mitigation	Crawl space	3
--	"	"	Basement	6
--	"	"	Basement wall penetration	6
--	"	"	Floor/wall joint	14
--	"	"	Hollow support post	9
--	"	"	Below slab	140
1	3/88	Passive on	Living room (above crawl space)	1.2
1	"	"	Basement	10.3
1	"	"	Inside north wall	4.6
1	"	"	Below slab	910
1	"	"	Inside vent pipe	368

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
12/86	Pre-mitigation	Living room (above CS)	13.2	Owner reported
"	"	Basement	20.0	"
8/87	Pre-mitigation	Uncertain	9.4,9.8	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS - HOUSE 069

Stage	Date	Location*	Suction** (inches H_2O)	Flow Rate (cfm)
1	3/88	Inside vent pipe	0.030 to 0.070	1 to 5
1	"	Test hole 1	0.000 to 0.017	--
1	"	Test hole 2	0.000 to 0.005	--
1	"	Test hole 3	-0.004	--
1	"	Test hole 4	-0.005	--

* Numbers refer to sub-slab test hole locations (see Figure 069-1). Weather 65 °F, windy, wind turbine spinning well.

** Negative suction indicates that area is pressurized relative to basement.

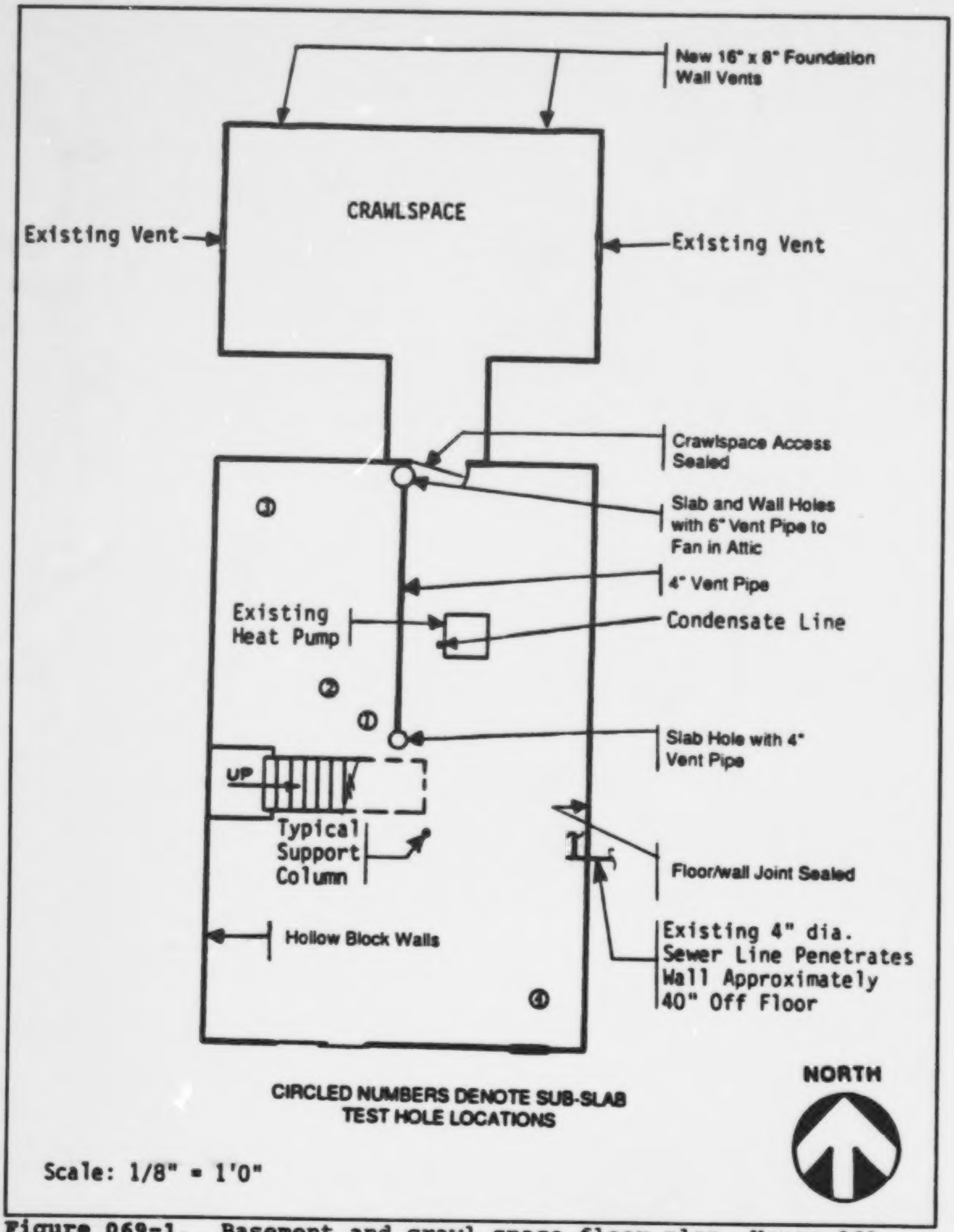

New 16" x 8" Foundation Wall Vents
CRAWLSPACE
Existing Vent
Existing Vent
Crawlspace Access Sealed
Slab and Wall Holes with 6" Vent Pipe to Fan in Attic
4" Vent Pipe
Existing Heat Pump
Condensate Line
③
②
①
Slab Hole with 4" Vent Pipe
UP
Typical Support Column
Floor/wall Joint Sealed
Hollow Block Walls
Existing 4" dia. Sewer Line Penetrates Wall Approximately 40" Off Floor
④
CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
NORTH
Scale: 1/8" = 1'0"

Figure 069-1. Basement and crawl space floor plan, House 069

HOUSE 074

Basement Measurements

Pre-mitigation Radon Levels	7.6-27.8 pCi/L
Stage 1 Post-mitigation Radon Levels	10.7-11.6 pCi/L
Stage 2 Post-mitigation Radon Levels	3.8-6.0 pCi/L

DESCRIPTION

This is a one-story house over an unfinished basement and an adjoining crawl space. The "crawl space" could better be described as an unpaved portion of the basement; it is full height, and has two doorways (without doors) which open into the basement. There is also an attached slab-on-grade garage. The house has hollow block foundation walls. The house was built in 1967, has a brick veneer on the exterior, and is located in a hilly residential area in Eldersburg, MD. A two-zone air electric heat pump system is used to heat the house. There is a wood stove in the basement and another on the first floor; neither is supplied with outside make-up air. The house is on city water. A basement/crawl space floor plan is shown in Figure 074-1.

The hollow concrete block basement walls have open top voids with sill plates resting above. Approximately 50 percent of the basement wall area is located below grade. The basement walls are penetrated by a public water pipe and electric wires. Some of the basement walls have been painted. The floor/wall joint is a perimeter expansion joint, containing asphalt-impregnated fiber material approximately 1/2 inch wide. One slab crack is present in the northeast basement corner. The basement slab is penetrated by a 4-inch sewer pipe, a water pipe for an outside spigot, and two support posts that are filled with concrete. There is no sump or perimeter drain tile.

An interior foundation wall separates the basement and crawl space.

As with the perimeter foundation walls, this wall is hollow block with open top voids. A sill plate rests on the wall and covers all but one of the top voids. The crawl space has 5 to 8 feet of headroom. There is a plastic vapor barrier on the crawl space floor; this plastic is not sealed to the walls.

ACTION - HOUSE 074

Stage 1

The mitigation system chosen for this house was passive sub-slab depressurization in the basement and passive sub-liner depressurization in the crawl space. The flue of the wood stove in the basement was to be used as the passive stack. Also, suspected radon gas entry routes in the basement were sealed.

In March 1988, a 4-1/2 inch diameter hole was drilled through the basement slab in the northwest corner. No sub-slab aggregate was observed. This was surprising, since pre-mitigation freon gas communication tests had indicated good sub-slab communication and sub-slab aggregate was expected to be present below the slab. In order to make a larger hole under the slab, a 2-foot by 2-foot hole was jackhammered where the first hole had been located. To reduce pressure losses in the system, eight cubic feet of sub-slab sand was excavated and replaced with 3/4-inch stone aggregate. A 4-inch PVC suction pipe was inserted to a depth approximately 1 foot below the slab, and several holes were drilled through the portion of the pipe located below the slab. The 4-inch pipe was connected to an 8-inch metal flue for the wood stove; this flue connected to the house chimney.

In the crawl space, a trench was excavated around the perimeter, and 4-inch perforated PVC pipe was placed in the trench, creating a complete loop. Sheets of 20-mil plastic membrane were placed over the crawl space floor, and were sealed against the foundation walls. This liner material was heavier than the 10-mil (equivalent) plastic used in House 047, because the fact that this stand-up "crawl space" had full-sized doorways to the basement indicated that there could be heavy traffic. Lap joints between membrane sheets were sealed with three rows of sealant. The water heater, located in the crawl space, was moved to the basement to facilitate crawl-space sealing. The crawl-space perforated PVC pipe was attached to a 4-inch PVC pipe that penetrated the foundation wall to the house exterior. A 6-inch pipe, to serve as the passive stack, was connected to the 4-inch pipe outdoors. The 6-inch stack was extended up the outside of the house and through the roof eave. A wind turbine was attached to the stack, and mounted on the roof. This stack was originally scheduled to run up the interior of the house, but was modified in the field at the request of the homeowner. Placing the vertical stack on the outside of the house does not take advantage of the thermal "stack effect" that would have been present had the stack been routed up to the roof inside the house.

The asphalt-impregnated fiber material in the floor/wall perimeter expansion joint was compressed, and the resulting channel was sealed with flowable urethane caulk. The northeast corner slab crack was ground out and sealed. The open blocks exposed in the basement window sills were sealed with expandable foam. An open top block on the interior foundation wall was not observed during mitigation work, and thus inadvertently was not sealed with foam. Urethane was used to seal the water pipe and the outside spigot water pipe wall penetrations.

In March 1988, suction and flow rate measurements were taken on a calm 35 °F day. With the basement wood stove off, the basement SSD pipe had no flow and a suction of 0.002 inches water relative to the basement. When the wood stove was operated, the suction pipe flow rate ranged from 0.0 to 0.5 cubic feet per minute (cfm) and the suction in the pipe increased to 0.029 inches water. However, 0.003 inches water of positive pressure existed below the slab 10 feet from the SSD pipe, indicating that most of the sub-slab was not influenced by the passive sub-slab depressurization system. With the wood stove off, a positive pressure of 0.005 in. WG was present inside the sub-liner depressurization pipe relative to the crawl space. This indicated that back drafting was probably occurring (i.e., outside air was flowing through the wind turbine into the SLD system). When the wood stove was operated, the positive pressure in the SLD pipe increased to 0.008 inches water. This might have been due to basement and crawl space depressurization resulting from wood stove operation. Measurements later in March, on another calm day (but warmer, 60 °F), no flow was detected in either the SSD or the SLD piping.

In April 1988, radon levels were measured with Pylon monitors. The basement concentration averaged 10.7 pCi/L, within the range of the pre-mitigation measurements. The crawl-space radon level was 11.6 pCi/L, somewhat lower than the pre-mitigation reading of 16.2 pCi/L obtained in January 1988; however, this might have been due to seasonal variations in the source term rather than a real effect of the passive system. These results suggest that the passive system is, at best, only marginally effective.

Additional Pylon measurements were made in June 1988. Throughout the 4-day test, the basement SSD pipe was disconnected, to permit assessment of the effect of the crawl space SLD system by itself. For the first two days of testing, the crawl space SLD pipe was also disconnected, to determine the current baseline, non-mitigated concentration. Under slightly windy conditions, the crawl space radon level with neither passive system operating was 4.1 pCi/L and the basement was 4.3 pCi/L. For the final two days, the crawl space SLD system was reconnected. Under very windy conditions, the crawl space radon level increased to 7.4 pCi/L and the basement level rose to 8.6 pCi/L. These data suggested that indoor radon concentrations increased with the passive crawl space depressurization system operating; however, this may have been caused by back drafting in the suction pipe resulting from the very windy conditions, or possibly from natural variations in the source term.

A problem arose from using the basement wood stove flue as a passive stack. A mixture of water and creosote periodically dripped from the joints in the flue, caused by water vapor being drawn from beneath the slab and condensing on the flue.

Stage 2

Due to the unacceptable performance of the passive depressurization system, modifications were made to improve sub-slab and sub-liner depressurization, and to prevent creosote from dripping into the basement.

In July 1988, the basement SSD pipe was detached from the wood stove flue and connected to the exterior 6-inch stack to which the crawl space SLD system was connected. The roof-mounted wind turbine was removed, and a Kanalflakt T2 6-inch in-line duct fan (270 cfm) was attached to the 6-inch vent pipe and mounted on the roof. The stack and fan were enclosed in a chase for appearance, and a rain hat was placed on top. Dampers were installed in the two suction pipes, and the flow rates from the SSD and SLD systems were balanced. After balancing, the crawl space SLD flow rate was 35 cfm, and the basement SSD flow rate was 31 cfm.

A fan control panel was installed in the basement, containing a power switch, an on/off light to indicate suction in the vent pipe, and a rheostat to adjust the fan speed.

In August 1988, the suction pipe flow rates were retested. The crawl space SLD flow rate was 64 cfm, and the basement SSD flow was 6 cfm. This shift in flow rates from July 1988 values may have been caused by changes in sub-soil conditions or by a shift in the damper positions.

Pylon measurements were taken in January 1989. With the fan off, the crawl space radon level was 13.1 pCi/L, and the basement level was 11.4 pCi/L. When the fan was turned on, the crawl space radon level decreased to 5.2 pCi/L, and the basement level decreased to 6.0 pCi/L.

Alpha-track detectors deployed from August 1988 to December 1988 measured radon levels of 4.4 pCi/L in the crawl space and 3.9 pCi/L in the basement. Another set of alpha-track detectors were deployed from December 1988 to March 1989; these cold-weather measurements showed a crawl space radon level of 3.9 pCi/L, and a basement level averaging 5.2 pCi/L. These data showed that although radon reductions were accomplished by the active depressurization system, additional mitigation steps would be needed to reduce the levels below EPA's recommended average action level of 4 pCi/L.

Subsequent suction field extension measurements confirmed that suction was not distributed underneath the entire basement slab. Another active SSD pipe was then added to the system, reducing levels below 4 pCi/L.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 074

Gamma radiation levels ranged from 8 uR/hr to 15 uR/hr in the basement and crawl space in June 1987. Freon gas communication tests were performed in October 1987. Freon gas was injected below the basement slab and detected in the exhaust of a vacuum placed in a test hole located in the northwest basement corner, approximately 30 feet away. The freon gas was detected after two minutes, indicating good sub-slab communication.

REMEDIATION SYSTEM - HOUSE 074

Stage	Date	System Description
1	3/88	Passive sub-slab depressurization using the wood stove flue as passive stack; passive sub-liner depressurization in the crawl space; and entry route sealing in basement.
2	7/88	Active sub-slab and sub-liner depressurization.

TEST DATA - HOUSE 074

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
-	1/88	43	Pre-mitigation	Crawl sp.	16.2	10-21
1	4/88	95	Passive on	Crawl sp.	11.6	3-16
1	"	"	"	Basement	10.7	3-17
1	6/88	45**	A	Crawl sp.	4.1	2.7-5.9
1	"	44***	B	"	7.4	3.7-11.3
1	"	45**	A	Basement	4.3	2.6-6.6
1	"	45***	B	"	8.6	4.7-12.5
2	1/89	44	Fan off	Crawl sp.	13.1	7.3-20.4
2	"	"	Fan on	"	5.2	3.7-7.7
2	"	"	Fan off	Basement	11.4	6.8-17.1
2	"	"	Fan on	"	6.0	4.5-8.6

* Test Condition A - SLD system off, SSD system off.
Test Condition B - SLD system on, SSD system off.
** Slightly windy during test.
*** Very windy during test.

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
2	8/88-12/88	Family room (above crawl space)	2.5, 2.8
2	"	Crawl space	4.4, 4.4
2	"	Basement	3.8, 4.1
2	12/88-3/89	Family room	3.9, 4.2
2	"	Crawl space	3.6, 4.2
2	"	Basement	4.4, 6.0

PYLON GRAB SAMPLES - HOUSE 074

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
-	6/87	Pre-mitigation	Family room (above crawl space)	2	0.012
-	"	"	Basement	13	0.035
-	"	"	Basement slab crack	80	-
-	"	"	Floor/wall joint	100	-
-	"	"	Crawl space, under plastic	320	-
-	10/87	Pre-mitigation	Family room	5.8	0.008
-	"	"	Basement	9.0	0.022
-	"	"	Crawl space	17.0	0.029
-	"	"	Below slab	1500	-
1	3/88	Passive on	Basement	12.2	-
1	"	"	Below slab	2051	-
1	"	"	SSD suction pipe	166	-

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
3/87	Pre-mitigation	Family room (above CS)	13.0	Owner reported
"	"	Basement	27.8	"
8/87	Pre-mitigation	Uncertain	7.6	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Test Condition	Location**	Suction*** (inches H_2O)	Flow Rate (cfm)
1	3/88	Wood stove off*	SSD pipe	0.002	0
1	"	Wood stove on*	"	0.029	0 to 0.5
1	"	"	Test hole 1	-0.003	--
1	"	Wood stove off*	SLD pipe	-0.005	--
1	"	Wood stove on*	"	-0.008	--
2	7/88	Fan on	SSD pipe	--	31
2	"	"	SLD pipe	--	35
2	8/88	Fan on	SSD pipe	--	6
2	"	"	SLD pipe	--	64

* Calm weather during test.

** Number refers to sub-slab test hole location (see Figure 074-1).

*** Negative suction indicates pressurization relative to house.

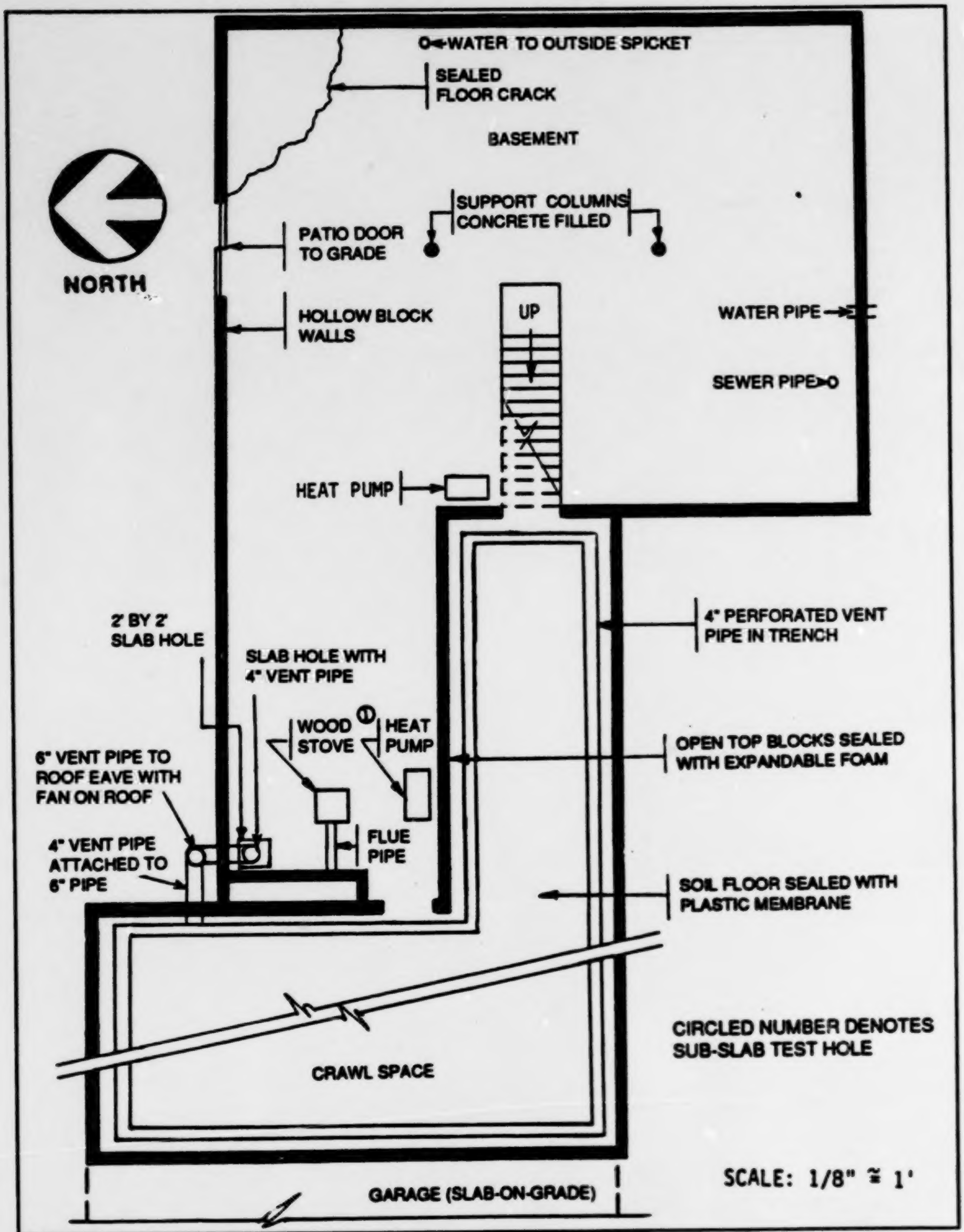

WATER TO OUTSIDE SPICKET
SEALED FLOOR CRACK
BASEMENT
SUPPORT COLUMNS CONCRETE FILLED
PATIO DOOR TO GRADE
NORTH
HOLLOW BLOCK WALLS
UP
WATER PIPE
SEWER PIPE
HEAT PUMP
4" PERFORATED VENT PIPE IN TRENCH
2' BY 2' SLAB HOLE
SLAB HOLE WITH 4" VENT PIPE
WOOD STOVE
①
HEAT PUMP
6" VENT PIPE TO ROOF EAVE WITH FAN ON ROOF
OPEN TOP BLOCKS SEALED WITH EXPANDABLE FOAM
4" VENT PIPE ATTACHED TO 6" PIPE
FLUE PIPE
SOIL FLOOR SEALED WITH PLASTIC MEMBRANE
CIRCLED NUMBER DENOTES SUB-SLAB TEST HOLE
CRAWL SPACE
SCALE: 1/8" ≅ 1'
GARAGE (SLAB-ON-GRADE)

Figure 074-1. Basement and crawl-space floor plan, House 074

HOUSE 076

Basement Measurements

Pre-mitigation Radon Levels	4.3-16.8 pCi/L
Stage 1 Post-mitigation Radon Levels	2.8-9.8 pCi/L
Stage 2 Post-mitigation Radon Levels	0.5-2.9 pCi/L

DESCRIPTION

This two-story house has an unfinished basement with poured concrete foundation walls and an adjoining crawl space. There is also an attached slab-on-grade garage and patio. The house was built in 1978, has aluminum siding, and is located on the top of a ridge several miles southwest of Damascus, MD. There is a forced air oil heating system and a fireplace in the living room. The house is served by city water. The basement and crawl-space floor plan is shown in Figure 076-1).

The basement has poured concrete walls that the homeowner has painted. The poured concrete wall separating the basement from the crawl space has a small access way with a plywood door; a forced-air heating duct penetrates this door. There are significant gaps around where the duct penetrates the door, and between the door and its frame. This concrete wall is penetrated by the main support beam; a gap between the concrete and the beam has been sealed with polyurethane caulk by the owner. The basement walls are also penetrated by the oil, sewer, and city water pipes. The basement slab is covered with floor tile and is penetrated by an old sewer pipe. A test hole drilled through the south corner revealed a plastic vapor barrier, but no aggregate was present. There is no sump or perimeter drain tile. The floor/wall joint appears to be a perimeter expansion joint which is apparently well closed by asphalt-impregnated fiber material, except for a few holes along the northwest side. The crawl space has forced air ducts passing through. It has a dirt floor that is partially covered with plastic sheets. The crawl space has poured concrete walls and two foundation vents that are partially obstructed. The house also has an attic fan.

ACTION - HOUSE 076

Stage 1

Pre-mitigation grab radon levels of 30.1 pCi/L in the basement and 16.7 in the crawl space indicated that the basement was the primary source of radon. (These grab radon samples were taken with the attic fan on and were much higher than with it off.) Basement slab cracks were suspected to exist under the floor tiles, since the floor/wall joint was sealed and the basement walls were poured concrete. To treat the major radon source, a passive sub-slab depressurization system was installed in March 1988 using the furnace flue as a passive stack.

A 4-1/2 inch diameter hole was drilled through the basement slab on the northeast side, immediately beside an interior frame wall separating the family room from the furnace room. About 10 gallons of dirt and stone were removed from under the hole. A 4-inch diameter PVC suction pipe was inserted into the hole, and the gap between the pipe perimeter and the concrete sealed. The 4-inch pipe was extended up along the interior frame wall, then through this wall to the furnace flue, approximately 5 feet away.

A new wooden crawl space door and frame were installed. The new frame permitted more effective sealing of the gap between the access way and the air duct. The door was tightly sealed against the door frame. The new frame was sealed against the concrete wall with caulk. Also, the oil line penetration through the concrete wall was caulked.

Measurements taken on a windy day in April 1988 inside the passive SSD pipe indicated a suction that ranged from 0.008 to 0.050 inches of water, but no measurable air flow, when the furnace was off. There was suction under the slab in three test holes, with one located in the far corner approximately 25 feet away. The suction in the pipe and in the three test holes with the furnace on was at least twice the suction with the furnace off. Therefore, most of the sub-slab area was under suction with the fan either on or off on this windy day.

Pylon tests performed in April 1988 measured radon levels of 0.8 pCi/L in the living room (located above the crawl space) and 3.0 pCi/L in the basement. These levels compare with pre-mitigation Pylon readings (in January 1988) of 4.3 pCi/L in the living area and 9.5 pCi/L in the basement. However, it was not clear whether these low levels post-mitigation levels in April were due to the passive system, or to the warm weather.

Pylon tests were repeated in November 1988 during mild weather with the passive system operating and, again, the radon levels were low. With the passive system on, the living room level was 0.9 pCi/L, and the basement level was 2.8 pCi/L. These data suggested that the passive system had reduced the radon levels from the pre-mitigation values measured the previous January. However, alpha-track detectors deployed from August 1988 to November 1988 measured 3.1 pCi/L in the living room and 9.8 pCi/L in the basement. This alpha-track data, which provided a better long-term measure of the average radon levels, suggested that the passive depressurization system was not fully successful in reducing the radon levels. This was the case, despite the April 1988 suction measurements which had demonstrated that most of the sub-slab area was being depressurized by the passive vent system on windy days or when the furnace was operated.

Stage 2

In December 1988, the passive depressurization system was disconnected from the furnace flue and actively depressurized with a fan. The piping from the 4-inch SSD pipe was extended to the east corner of the basement, where it penetrated the band joist. A Fantech in-line duct fan (270 cfm) was installed on the 4-inch pipe inside the basement, near the band joist. The fan was placed inside the basement at the request of the homeowner. An elbow was installed on the pipe outside the house to direct the exhaust toward the side of the house. A screen was placed at the end of the pipe to keep out debris.

A fan control panel was installed in the basement, containing a power switch, an on/off light to indicate suction in the pipe, and a rheostat to adjust the fan speed.

In January 1989, following Stage 2 modifications, Pylon measurements with the fan off indicated 4.5 pCi/L in the living room and 8.9 pCi/L in the basement. With the fan operating, the levels decreased to 0.6 pCi/L in the living room and 0.5 pCi/L in the basement. The living room level of 0.6 pCi/L was slightly less than the 0.9 pCi/L Pylon measurement which had been obtained with the passive system in November; and the basement radon level of 0.5 pCi/L was lower than the passive system level of 2.8 pCi/L. Low radon levels were confirmed by alpha-track detectors from November 1988 to February 1989 that averaged 0.7 pCi/L in the living room and 2.0 pCi/L in the basement. The first month of this alpha-track testing had been with the passive system in place, and the final 2 months were with the active system operating; this suggests that the radon concentrations probably would have been even lower if the active system had been in operation during the entire measurement period.

In May 1989, suction tests were repeated in the three sub-slab test holes. Suction ranged from 0.088 to 0.831 in. WG in the test holes, indicating the expected dramatic improvement over the suction created by the passive depressurization system.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 076

In October 1987, freon gas communication tests were made that indicated good sub-slab communication. Freon gas was injected into a hole drilled through the slab in the south basement corner. Freon gas was detected in 2 minutes at a second test hole approximately 25 feet away.

REMEDIATION SYSTEM - HOUSE 076

Stage	Installation Date	System Description
1	3/88	Passive sub-slab depressurization using the furnace flue, and improved crawl space isolation from basement.
2	12/88	Active sub-slab depressurization.

TEST DATA - HOUSE 076

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
--	1/88	41	Pre-mitigation	Living rm (above CS)	4.3	2-8
--	"	"	"	Basement	9.5	6-15
1	4/88	95	Passive on	Living rm	0.8	0-2
1	"	"	"	Basement	3.0	0-9
1	11/88	64	Passive off	Living rm	4.7	0.5-7.7
1	"	26	Passive on	"	0.9	0.4-1.4
1	"	64	Passive off	Basement	14.2	3.4-20.7
1	"	26	Passive on	"	2.8	1.6-4.8
2	12/88	47	Fan off	Living rm	4.5	3.2-6.3
2	"	31	Fan on	"	0.6	0.2-0.9
2	"	45	Fan off	Basement	8.9	6.3-17.4
2	"	28	Fan on	"	0.5	0.2-0.7

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	8/09/88-11/15/88	Living room	2.7, 3.4
1	"	Basement	9.7, 9.8
1,2	11/15/88-2/16/89	Living room	0.7, 0.7
1,2	"	Basement	*

* Outside QC goals.

PYLON GRAB SAMPLES - HOUSE 076

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	6/87	Pre-mitigation	Living room	1.1	0.005
--	"	"	Basement	10.0	0.068
--	"	"	Crawl space	3.3	0.070
--	10/87	Pre-mitigation	Living room	4.6	0.016
--	"	"	Basement (central)	3.4	0.022
--	"	"	Basement (west)	6.4	0.017
--	"	"	Crawl space	2.5	0.002
--	"	"	Living room	1.9*	—
--	"	"	Basement (central)	30.1*	—
--	"	"	Crawl space	16.7*	--
1	4/88	Passive on	Basement	0.2	--
1	"	"	Inside SSD pipe	968	--

* With attic fan on.

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
<3/87	Pre-mitigation	Basement	16.8	Owner reported
8/87	Pre-mitigation	Uncertain	4.3-7.9	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Test Condition	Location*	Suction (inches H_2O)	Flow Rate (cfm)
1	4/88	Furnace off	SSD pipe	0.008 to 0.050	0
1	"	"	Test hole 1	0.007 to 0.024	-
1	"	"	Test hole 2	0.002 to 0.004	-
1	"	"	Test hole 3	0.001	-
1	"	Furnace on	SSD pipe	0.076	0
1	"	"	Test hole 1	0.035	-
1	"	"	Test hole 2	0.024	-
1	"	"	Test hole 3	0.003	-
2	5/89	Fan on high	SSD pipe	1.62	26
2	"	"	Test hole 1	0.831	-
2	"	"	Test hole 2	0.357	-
2	"	"	Test hole 3	0.088	-

* Numbers refer to sub-slab test hole locations (see Figure 076-1).

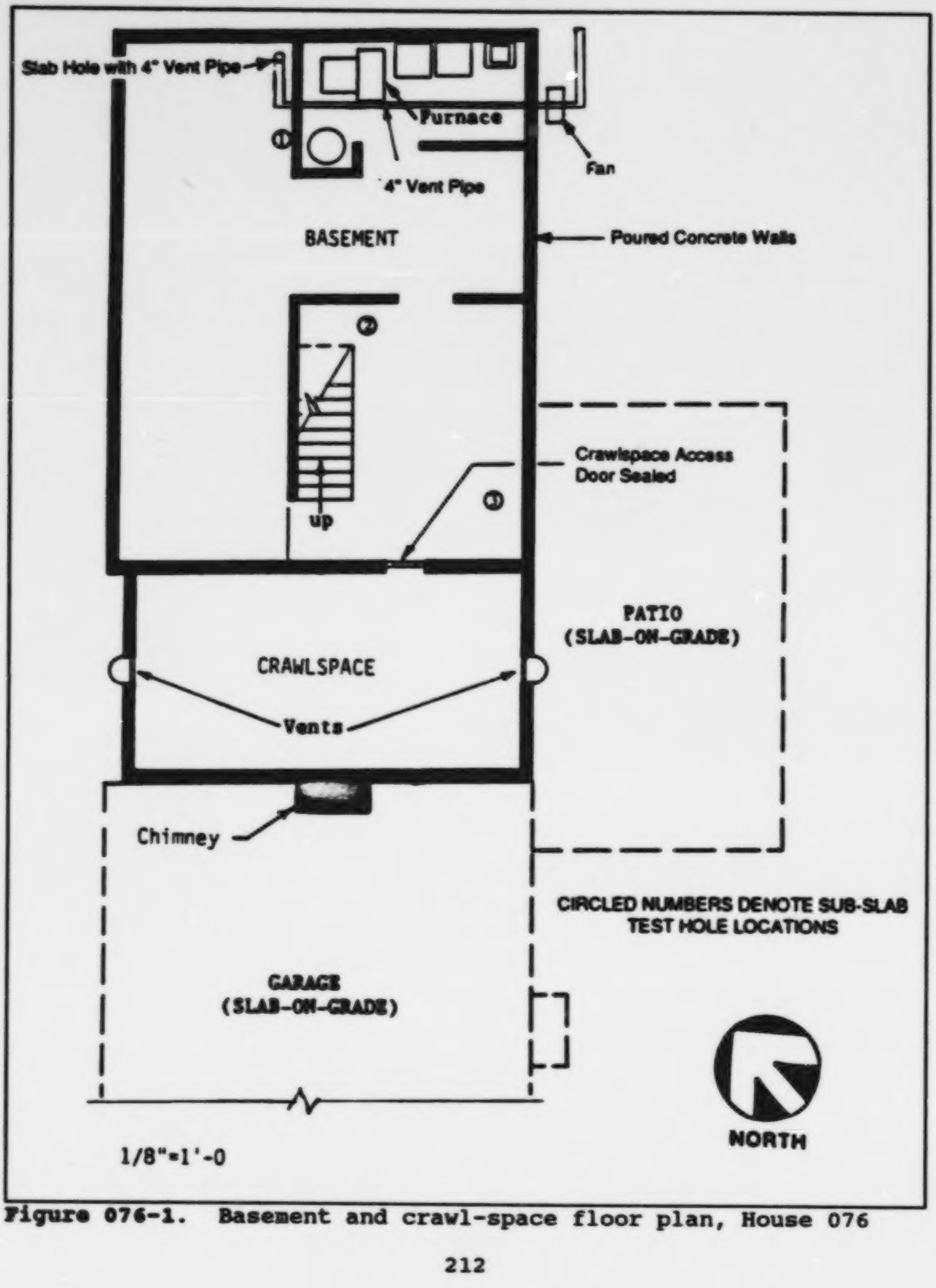

Slab Hole with 4" Vent Pipe
Furnace
4" Vent Pipe
Fan
①
BASEMENT
Poured Concrete Walls
②
up
③
Crawlspace Access Door Sealed
PATIO (SLAB-ON-GRADE)
CRAWLSPACE
Vents
Chimney
CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
GARAGE (SLAB-ON-GRADE)
NORTH
1/8"=1'-0

Figure 076-1. Basement and crawl-space floor plan, House 076

HOUSE 079

Basement Measurements	
Pre-mitigation Radon Levels	2.8-24.0 pCi/L
Stage 1 Post-mitigation Radon Levels	0.6-2.6 pCi/L
Stage 2 Post-mitigation Radon Levels	0.4-0.9 pCi/L

DESCRIPTION

This two-story house has an unfinished basement with poured concrete foundation walls. There is an attached slab-on-grade garage. The house was built in 1984 on gradually sloping land and is located in a subdivision a few miles southwest of Gaithersburg, MD. The house has forced-air electric heating that is supplemented with a living room fireplace, which the homeowner uses infrequently. There is an attic fan and a garage fan. The house is served by city water. The basement floor plan is shown in Figure 079-1.

The basement walls are poured concrete with brick face texture, and have no noticeable cracks. The poured concrete wall is interrupted on the west side by a 6-foot-long hollow block segment that is the foundation for a fireplace on the floor above. A joint is formed on each side of the block wall, where it meets the poured concrete wall. The segment of block wall appears to be resting on top of the basement slab. The north basement wall is penetrated by a public water pipe. The basement slab has several minor cracks and a small patched area. Five plumbing pipes and four support posts penetrate the basement slab. The attached garage slab has one major crack. A perimeter floor/wall expansion joint exists that ranges from 1/8 inch to 1/2 inch in width. There is a plastic lined sump that is open to the soil underneath and does not have a sump pump. No perimeter drain tiles are present in the sump.

ACTION - HOUSE 079

Stage 1

In March 1988, a passive sump depressurization system was installed in conjunction with floor/wall joint sealing. A flat plywood sump cover was bolted to the slab, and sealed with a bead of non-flowable urethane caulk between the plywood and the slab. A 4-inch diameter PVC suction pipe was placed through the plywood cover and sealed around the perimeter. The suction pipe was extended up to the basement ceiling, then routed horizontally to the center of the basement, where a chase is located. Three 90° elbows and four 45° elbows had to be used to direct the pipe around various ducting and utility pipes, to reach the center of the basement from the sump pit. The 4-inch piping was run up the chase to the first floor, where it was increased to 6-inches in diameter before being extended up to the attic and through the roof. It was necessary to re-route the plumbing and air ducts that were enclosed in the chase, to accommodate the stack. The 6-inch stack was covered with fiberglass insulation in the attic, and connected to a 12-inch wind-driven turbine mounted on the roof. The attic was pre-wired in the event that a fan might be required later.

A 75-pound jackhammer was used to compress the expansion joint material in the floor/wall joint. Large voids in the floor/wall joint were filled, and flowable urethane was applied as a sealant. Also, several slab cracks were routed out and sealed with flowable urethane caulk; two small holes in the south wall were also sealed with caulk.

Suction and flow rate measurements were taken in the passive sump depressurization pipe in April 1988. A very slight pipe suction of 0.003 inches H_2O relative to the basement was measured with the wind turbine stationary. Some flow was present in the pipe, but could not be measured.

A Pylon measurement was made in April 1988, and a second in May, with the passive system operating. A monitor at the west end of the basement (adjacent to the slab-on-grade garage) measured radon levels of 0.7 pCi/L in April (down from 3.0 pCi/L with the system disabled), and 0.9 pCi/L in May (down from 3.1 pCi/L with the system off). Concentrations measured on the opposite end of the basement at the same time were 0.8 and 0.8 pCi/L, respectively. Alpha-track detectors were deployed from June 1988 to September 1988. The radon level in the basement (west end) was 2.0 pCi/L and in the kitchen was 1.4 pCi/L. The basement level was much lower than the January 1988 pre-mitigation level of 24.0 pCi/L. However, much of this apparent reduction was due probably due to seasonal fluctuations rather than the mitigation system.

Additional Pylon tests in December 1988 measured 0.6 pCi/L radon in the basement (west end) and 0.3 pCi/L in the kitchen. These results indicated that the cool weather radon levels during the four day test were below the EPA action level. Results for alpha-track detectors in place from September 1988 to December 1988 indicated an average basement radon level of 2.4 pCi/L, demonstrating that the passive depressurization system had been effective on a long-term basis during cool weather. The passive SSD system in this house was the most effective of the passive systems tested.

Stage 2

In December 1988, the passive sump depressurization system was activated. This action was taken before the September through December alpha-track results had been received back from the laboratory, and thus before the long-term effectiveness of this system was known. The system activation was implemented before the alpha-track results were received because it was necessary to complete the final changes to all of the mitigation systems in this project on the schedule required by the contract.

The passive system was converted to an active system by removing a portion of the 6-inch stack in the attic and installing a Fantech Model R-150 (270 cfm) in-line duct fan. The wiring installed in the attic during Stage 1 was used. As a cost-saving measure, the wind turbine was not replaced with a rain hat; the turbine was not expected to have a large effect on the air flow.

A fan control panel was installed in the basement containing a power switch, an on/off light to indicate suction in the vent pipe, and a rheostat to adjust the fan speed.

Pylon measurements taken in January 1989 showed that the active system radon levels were lower than the passive system values. The basement (west end) level was 0.4 pCi/L, and the kitchen level was 0.0 pCi/L.

Alpha-track detectors were deployed from December 1988 to March 1989 to measure Stage 2 radon levels. The radon level in the kitchen averaged 0.9 pCi/L, and the level in the basement averaged 0.7 pCi/L. Thus, by activating the depressurization system, lower radon levels were achieved.

Suction and flow rate measurements were taken on a slightly breezy day in May 1989. Data was collected with the fan turned off; this would be equivalent to having the Stage 1 passive system operating, since the wind turbine had been left in place. With the fan off, the pipe suction relative to the basement ranged from 0.000 to 0.044 inches of water, and the flow rate was 0.5 cfm. Suction in a sub-slab test hole located 12 feet from the sump ranged from 0.000 to 0.038 inches of water; suction in a test hole 40 feet from the sump ranged from 0.000 to 0.020 inches of water. These data demonstrated that much of the sub-slab area was being influenced by the passive depressurization system, and explained the significant reductions in radon levels realized by the passive system. When the fan was turned back on, suction in the two sub-slab test holes ranged from 0.883 to 0.915 inches of water, confirming that greater suctions were created by the active system.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 079

Gamma radiation measurements taken in June 1987 indicated 6 uR/hr in the basement. Freon gas communication tests performed in October 1987 indicated moderate sub-slab communication. Freon gas was injected into a hole drilled through the slab in the southwest corner of the basement. When suction was applied to the sump, located approximately 35 feet away from the test hole, freon was detected in the vacuum exhaust after four minutes. This result suggested a poorer sub-slab communication than in fact was encountered when the systems were installed.

REMEDIATION SYSTEM - HOUSE 079

Stage	Installation Date	System Description
1	3/88	Passive sub-slab depressurization via the sump, and entry route sealing.
2	12/88	Active sub-slab depressurization via the sump.

TEST DATA - HOUSE 079

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
--	1/88	48	Pre-mitigation	Basement (west)	24.0	14-29
--	"	"	"	Basement (east)	17.3	11-21
1	4/88	48	Passive off	Bsmt (W)	3.0	1-6
1	"	44	Passive on	"	0.7	0-1
1	"	48	Passive off	Bsmt (E)	2.8	1-5
1	"	44	Passive on	"	0.8	0-1
1	5/88	46	Passive off	Bsmt (W)	3.1	1.0-5.5
1	"	44	Passive on	"	0.9	0.4-1.2
1	"	46	Passive off	Bsmt (E)	2.4	0.6-4.6
1	"	44	Passive on	"	0.8	0.4-1.2
1	12/88	89	Passive on	Bsmt (W)	0.6	0.2-1.0
1	"	"	"	Kitchen	0.3	0.0-0.8
2	1/89	93	Fan off	Bsmt (W)	0.8	0.2-1.3
2	"	37	Fan on	"	0.4	0.0-0.9
2	"	93	Fan off	Kitchen	0.7	0.2-1.5
2	"	37	Fan on	"	0.0	--

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	6/1/88-9/8/88	Kitchen	1.3, 1.4
1	"	Basement (west)	1.9, 2.1
1	9/8/88-12/13/88	Kitchen	*
1	"	Basement (west)	2.2, 2.6
2	12/13/88-3/15/89	Kitchen	0.6, 1.1
2	"	Basement (west)	0.4, 0.9

* Data outside QC goals.

PYLON GRAB SAMPLES - HOUSE 079

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	6/87	Pre-mitigation	Dining room	6.4	0.032
--	"	"	Basement	11.4	0.086
--	10/87	"	Dining room	8.7	0.052
--	"	"	Basement (west)	49.2	0.277
--	"	"	Basement (east)	56.0	0.281
1	4/88	Passive on	Basement	1.1	--
1	"	"	In DTD pipe	2163	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
11/86	Pre-mitigation	First floor	10.6	Owner reported
"	"	Basement	20.2	"
2/87	Pre-mitigation	In sump hole	148.2	"
8/87	Pre-mitigation	Uncertain	12.4,12.5	Owner deployed
1/88	Pre-mitigation	Basement	17.2	Deployed by project member

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Location*	Suction (inches H_2O)	Flow Rate (cfm)
1	4/88	DTD pipe	0.003	**
2	5/89	DTD pipe	0.000 to 0.044	0.5
2	"	Test hole 1	0.000 to 0.038	-
2	"	Test hole 2	0.000 to 0.020	-
2	"	DTD pipe	1.28	47
2	"	Test hole 1	0.915	-
2	"	Test hole 2	0.883	-

* Numbers refer to sub-slab test hole locations (see Figure 079-1). Weather 45 °F, calm during 4/88 testing; slightly breezy during 5/88 testing.

** There was some flow in the vent pipe, but it could not be measured.

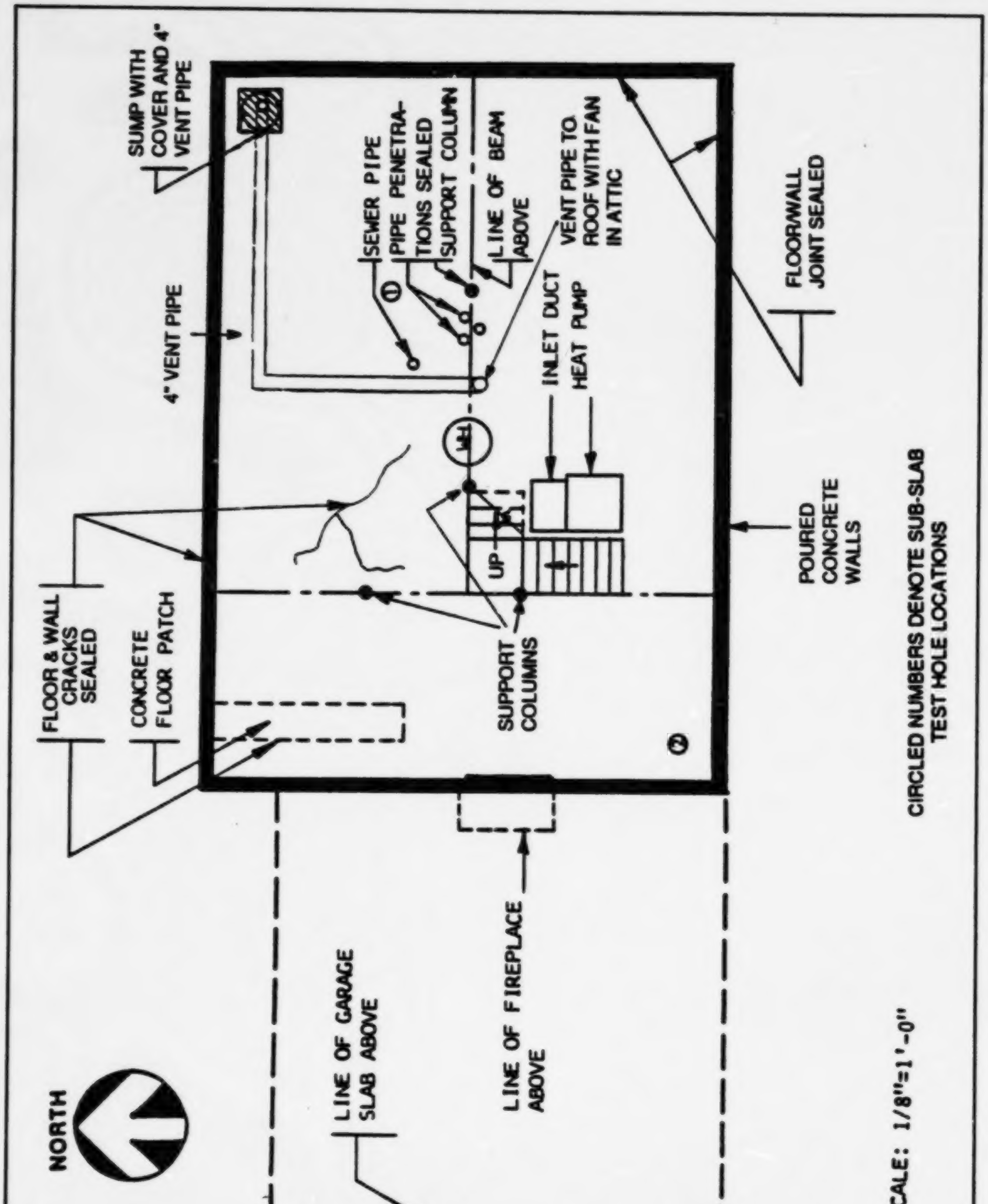

NORTH
LINE OF GARAGE SLAB ABOVE
LINE OF FIREPLACE ABOVE
SCALE: 1/8"=1'-0"
FLOOR & WALL CRACKS SEALED
CONCRETE FLOOR PATCH
SUPPORT COLUMNS
UP
②
CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
POURED CONCRETE WALLS
INLET DUCT
HEAT PUMP
WH
4" VENT PIPE
①
SEWER PIPE
PIPE PENETRATIONS SEALED
SUPPORT COLUMN
LINE OF BEAM ABOVE
VENT PIPE TO ROOF WITH FAN IN ATTIC
SUMP WITH COVER AND 4" VENT PIPE
FLOOR/WALL JOINT SEALED

Figure 079-1. Basement floor plan for House 079

HOUSE 096

Basement Measurements	
Pre-mitigation Radon Levels	6.9-23.0 pCi/L
Stage 1 Post-mitigation Radon Levels	1.9-8.6 pCi/L
Stage 2 Post-mitigation Radon Levels	0.5-0.7 pCi/L

DESCRIPTION

This one-story house has an unfinished basement with hollow block walls, and an adjoining slab-on-grade wing. It also has an attached slab-on-grade breezeway and garage. A new paved crawl-space wing was added during the course of this project. The house was built in 1978, has aluminum siding, and is located on gradually sloping land in a subdivision a few miles south of Westminster, MD. There is a forced-air oil heating system and a first floor fireplace that is rarely used. The house has a private well. The basement and upstairs floor plans are shown in Figures 096-1 and 096-2, respectively.

The south basement wall is above grade, and the other three are below grade. Three of the hollow block basement walls have solid cap blocks, and the other wall is covered with a sill plate, making it difficult to verify the presence of a cap block. The south wall has two top blocks with open voids. The basement walls have many cracks, and the south wall has grout missing between many of the blocks. The basement walls are penetrated by a 4" sewer pipe, a well water pipe, an oil pipe, and two electrical wires. The basement floor/wall joint is very tight and the basement slab has many interior cracks. The basement has a sump, with aggregate visible at the bottom. There are two perimeter drain tiles entering the sump. It is not known if the drain tile forms a complete loop, or if the drain tile is interior or exterior. An exterior stairwell drain empties to the sump. The family room, dining room, laundry room, and bathroom are located in the slab-on-grade part of the house. Forced-air supply ducts from the furnace in the basement are located under the slab on grade, and no aggregate is present under that slab.

The new crawl-space wing was added during spring of 1988, between Stages 1 and 2 of this project. This "crawl space" has a poured concrete floor which is on the same level as the original basement slab, and has enough headroom for a person to stand. The crawl-space "foundation wall" is an above-grade frame wall, and does not completely isolate the crawl space from the outdoors (due to large gaps between the siding and the slab in some areas). Because of the significant natural ventilation that would be expected under these circumstances, this new structure was not expected to affect the house radon levels significantly.

ACTION - HOUSE 096

Stage 1

A passive depressurization system was chosen for this house, combining drain tile depressurization via the basement sump, and sub-slab depressurization under the slab on grade. The basement DTD system had its own 6-inch passive stack, while the two slab-on-grade SSD pipes used the furnace flue as the stack. Radon entry route sealing was also carried out in the basement. A passive system was chosen since indoor radon levels appeared only moderately elevated in the living area (4.3 pCi/L in the laundry room on the slab-on-grade during an October 1987 Pylon measurement).

In November 1987, a thick plastic cover was installed over the sump, bolted to the slab; the seam between the cover and the slab was sealed with silicone caulk. There was a submersible pump in the sump. All penetrations through the cover were also sealed with silicone. An A/C condensate drain line that had drained into the sump was one of the penetrations through the cover; to prevent air from being drawn into the sump via this line, the end in the sump was submerged in a plastic bucket containing water that served as a trap. The exterior stairwell drain pipe also drained into the sump; this pipe, too, was placed into the bucket trap. A 4-inch PVC suction pipe was inserted into the sump cover. This pipe was routed, via four 90° elbows, over to the center of the north wall of the basement; it penetrated this stem wall, then turned up through the pantry closet on the slab-on-grade wing. In the closet, it was expanded to 6-inches in diameter; this 6-inch stack was extended up through the attic to the roof. The stack was insulated in the attic with fiberglass insulation. A roof-mounted wind turbine was attached to the top of the stack.

Two holes were drilled through the north basement wall below the level of the adjoining slab, and 3-inch diameter metal suction pipes were inserted into the holes to depressurize beneath the slab-on-grade. These two pipes -- one about 5 ft away from both the east and west walls -- penetrated the stem wall about 16 in. below the adjoining slab, because the furnace air ducts prevented the pipes from being placed higher, closer to the bottom of the slab. Thus, to the extent that there may have been any aggregate under the adjoining slab, these pipes would not have entered that aggregate layer. The two pipes were attached to the furnace flue to serve as the passive stack.

The space around the heating ducts (where they penetrated the north basement wall to service the adjoining slab) was sealed with expandable foam. Likewise, the open top voids on the north basement wall were sealed with foam. Several floor cracks were ground out and sealed using non-flowable polyurethane caulk. Major wall cracks in the basement, and the plumbing pipes in the bathroom (on the slab-on-grade), were sealed. Approximately 1/3 of the floor/wall joint was sealed with non-flowable urethane caulk. The remainder of the floor/wall joint was not sealed because it was generally tight, although in a few places the gap was up to 1/64 in. wide.

In November 1987, Pylon measurements were made with the passive system operating. The laundry room radon level was 2.5 pCi/L and the basement was 4.4 pCi/L, indicating that the mitigation system had reduced the radon levels. However, a final decision on the effectiveness of the system would have to be reserved until long-term alpha-track data were available.

To ensure that the use of the furnace flue as a passive stack did not interfere with the draft, carbon monoxide levels were measured in the basement during furnace operation. These levels were found to be below 3 ppm.

Suction and flow rate measurements were taken in November 1987. During testing, the weather was calm; the wind turbine for the basement DTD system was stationary. The suction in the DTD suction pipe relative to the basement ranged from 0.000 to 0.001 inches of water, and the flow was 0.0 to 0.1 cfm, demonstrating that on the test day, the DTD system was probably not effectively treating the basement sub-slab. With the furnace operating, the slab-on-grade SSD pipe nearest the east wall had 0.125 in. WG suction and 4 cubic feet per minute (cfm) flow, indicating that the depressurization system probably was producing suction under at least part of the slab on grade. These measurements fell to 0.015 in. WG and 0.5 cfm when the furnace was off.

Suction and flow rate measurements were repeated in March 1988. During testing, there was a slight breeze and the wind turbine for the DTD system was spinning. The flow rate in the DTD piping ranged from 13 to 19 cfm, and no suction could be detected.

According to this data, even when the turbine was spinning, the turbine was not creating measurable suction in the suction pipe, and probably was not producing any suction under the basement slab. With the furnace on, the slab-on-grade SSD pipe suction was 0.037 inches of water and the flow rate was 17 cfm, indicating that this system probably was having an impact on the slab-on-grade.

Alpha-track detectors were deployed from December 1987 to March 1988. The basement radon level averaged 7.6 pCi/L, which showed an improvement over pre-mitigation values but demonstrated that additional mitigation work would be needed.

In July 1988, a check valve was installed in the sump pump discharge line to prevent air from being drawn into the sump through the line; it was hoped that this step would improve the passive suction under the basement slab. Also, freon gas tests verified that the exterior stairwell drain pipe was effectively trapped. Alpha-track detectors deployed from June 1988 to September 1988 with the passive system operating measured 4.3 pCi/L in the basement. This decrease in the basement radon level from the 7.6 pCi/L measured in December through March, may have been due to seasonal variations or due to the installation of the check valve.

In July 1988, the north and south block basement wall radon levels were tested with Pylons. The north wall was 79.2 pCi/L with the passive system off, and decreased to 49.6 pCi/L with the system on. The south wall was 20.6 pCi/L with the system off, and 11.6 pCi/L with the system on. These data indicate the basement walls to be a radon source that is decreased when the passive system is operated.

The effect on radon levels of operating the central house fan (with the A/C on) was tested in July 1988. It was hoped that by forcing air through the ducts underneath the slab-on-grade, the area below the slab-on-grade would become pressurized, possibly preventing soil gas entry into, or diluting the radon in, the sub-slab region. With the central house fan on continuously, the radon level in the laundry room on the slab-on-grade wing was 4.6 pCi/L. However, when the central house fan was returned to the automatic setting (fan running periodically for the central air conditioning during the warm weather), the radon level decreased to 2.7 pCi/L. These data showed that operating the central house fan continuously did not lower the radon level, and actually caused the level to rise.

The passive system may have had a greater effect on radon levels if additional radon gas entry route sealing had been performed. Several hairline cracks in the basement walls, and the two open top voids on the south basement wall, could have been sealed. The wall penetrations and the remainder of the floor/wall joint, which is fairly tight, could have been sealed. Also, the basement walls could have been painted with sealant.

Stage 2

Rather than attempt additional passive techniques, the radon mitigation system was activated in December 1988. The slab-on-grade SSD pipes were disconnected from the furnace flue, and attached to the basement DTD pipe. A portion of the 6-inch stack in the attic was removed, and a Fantech in-line duct fan (270 cfm) was installed. Dampers were installed in the pipes, and the flow rates from the SSD and DTD systems were balanced.

A fan control panel was installed in the basement, containing a power switch, an on/off light to indicate suction in the vent pipe, and a rheostat to adjust the fan speed.

Alpha-track detectors deployed from January 1989 to April 1989 measured 0.3 pCi/L of radon in the laundry room (slab-on-grade), with the active system operating; the basement level was 0.7 pCi/L. The concentration in the new crawl-space addition was 0.4 pCi/L. These data demonstrated that the active system was effective.

Suction field extension under the basement slab was measured in May 1989. With the active depressurization system operating, no suction (0 in. WG) was measured in two sub-slab test holes, one located 2 ft from the sump, and the other 13 ft. This might have been because communication under the central part of the slab was not sufficient to permit suction from extending from the perimeter drain tiles. Perhaps radon reduction performance was so good because the main entry routes were around the perimeter, which the DTD system might have been effectively treating.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 096

Gamma radiation levels measured in June 1987 were 8 to 9 uR/hr in the basement and 10 uR/hr in the family room. Freon gas communication tests were conducted in July 1987. Freon gas was injected into the sump and was detected in the exhaust of a vacuum placed in a test hole located approximately 45 feet away. The freon gas was detected in 45 seconds, indicating good sub-slab communication.

REMEDIATION SYSTEM - HOUSE 096

Stage	Installation Date	System Description
1	11/87	Passive two-point sub-slab depressurization under the slab on grade, using the furnace flue as a stack; passive drain tile depressurization in basement; and entry route sealing.
2	12/88	Active two-point SSD (slab on grade) and DTD (basement).

TEST DATA - HOUSE 096

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
-	10/87	44	Pre-mitigation	Laundry rm (SOG)	4.3	0-9
-	"	45	"	Basement	23.0	16-33
1	11/87	44	Passive on	Laundry rm	2.5	0-11
1	"	"	"	Basement	4.4	0-8
1	7/88	38	Passive off	Laundry rm	3.2	1.5-6.8
1	"	42	Passive on	"	2.3	1.3-3.9
1	"	38	Passive off	Basement	6.9	2.5-14.3
1	"	40	Passive on	"	4.3	3.1-6.8
1	"	38	Passive off	North block wall	79.2	23.8-146.2
1	"	41	Passive on	"	49.6	15.6-106.2
1	"	38	Passive off	South block wall	20.6	2.4-60.9
1	"	41	Passive on	"	11.6	3.0-52.5
1	7/88	48	AC on continuously*	Laundry rm	4.6	1.4-9.4
1	"	41	AC on periodically*	"	2.7	1.4-5.0
1	"	48	AC on continuously*	Basement	3.9	1.1-8.1
1	"	41	AC on periodically*	"	1.9	0.6-3.6
1	12/88	93	Passive on	First floor	1.0	0.4-2.4
2	1/89	45	Active off	Laundry rm	2.2	0.4-6.3
2	"	"	Active on	"	0.4	0.1-0.8
2	"	45	Active off	Basement	7.0	1.3-17.5
2	"	"	Active on	"	0.5	0.0-1.0

* With passive system on

ALPHA-TRACK DETECTOR MEASUREMENTS - HOUSE 096

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	12/11/87-3/7/88	Laundry room (slab-on-grade)	*
1	"	Basement	6.6, 8.6
1	3/7/88-6/17/88	Laundry room	1.8, 2.3
1	"	Basement	4.8, 4.9
1	6/17/88-9/29/88	Laundry room	1.4, 2.0
1	"	Basement	4.0, 4.5
1,2	9/29/88-1/11/89	Laundry room	1.1
1,2	"	Basement	2.5, 3.2
2	1/11/89-4/13/89	Laundry room	< 0.3, 0.4
2	"	New addition	< 0.3, 0.5
2	"	Basement	0.6, 0.7

* Data outside QC goals.

PYLON GRAB SAMPLES

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
-	6/87	Pre-mitigation	Family room (slab on grade)	10.6	0.073
-	"	"	Basement	34	0.22
-	7/87	Pre-mitigation	Laundry room (SOG)	3.6	0.009
-	"	"	Basement (average)	9.5	0.028
-	"	"	Bsmt block wall (average)	183	--
-	"	"	Bsmt slab crack	156	--
1	3/88	Passive on	Basement	7.5	--
1	"	"	Below SOG slab	117	--
1	"	"	Bsmt block wall	348	--
1	"	"	Inside sump	30.0	--
1	7/88	Washing machine on	New laundry room	11.6	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
2/87	Pre-mitigation	Bedroom	15.7	Owner reported
8/87	Pre-mitigation	Basement	16.2, 17.0	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS - HOUSE 096

Stage	Date	Test Condition	Location*	Suction (inches H_2O)	Flow Rate (cfm)
1	11/87	Passive on (furnace off)	Basement DTD pipe	0 to 0.001	0 to 0.1
1	"	"	Slab-on-grade SSD pipe	0.015	0.5
1	"	Passive on (furnace on)	"	0.125	4
1	3/88	Passive on (furnace on)	DTD pipe	0	13 to 19
1	"	"	SSD pipe	0.037	17
2	5/89	Active on	DTD pipe	0.032	440
2	"	"	SSD pipe	0.237	460
2	"	"	Test hole 1	0.000	--
2	"	"	Test hole 2	0.000	--

* Numbers in the "Location" column refer to sub-slab test hole locations shown in Figure 096-1.

Weather: No wind, turbine stationary for 11/87 measurements; slight breeze, turbine spinning for 3/88 measurements.

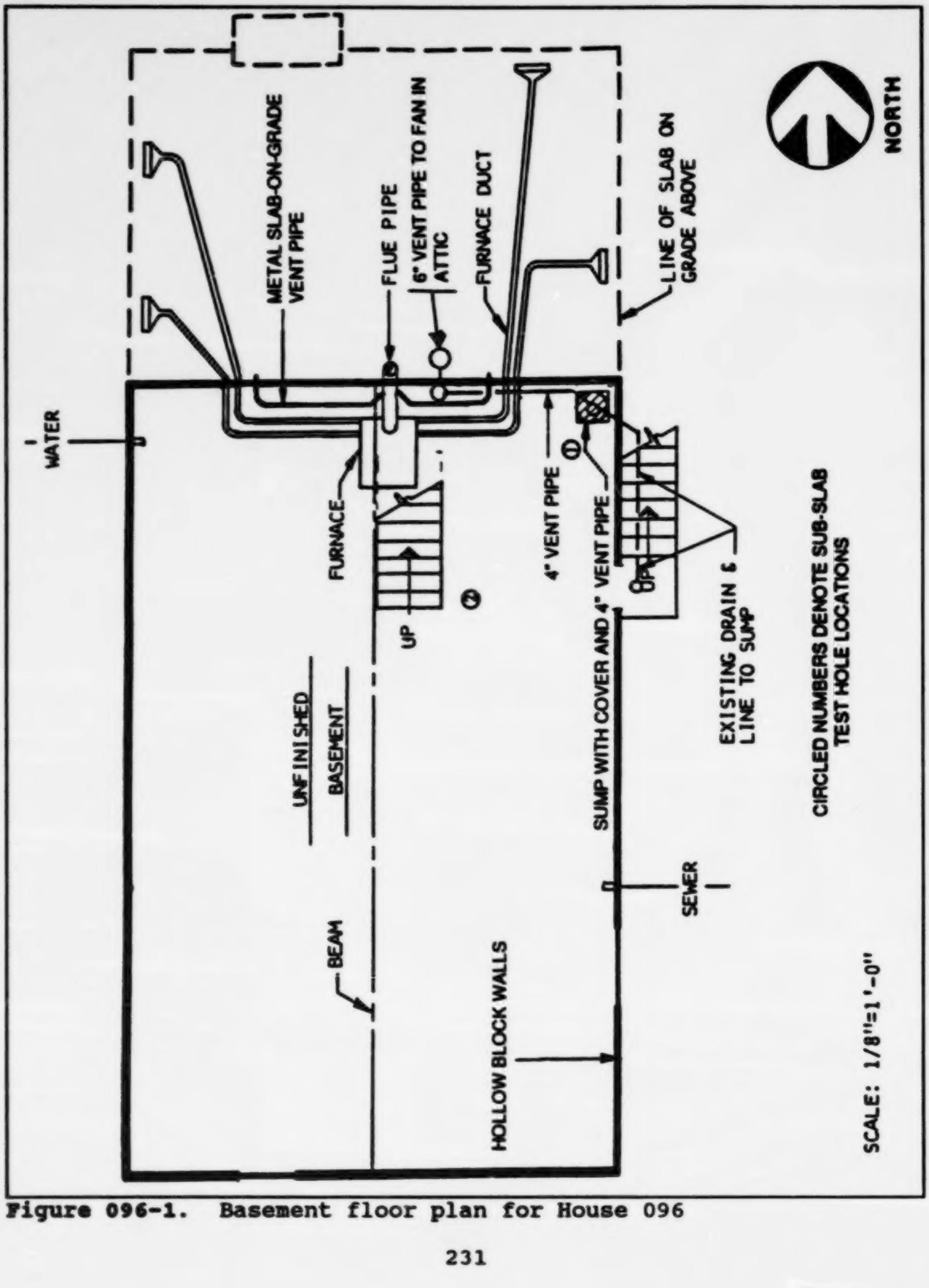

WATER
METAL SLAB-ON-GRADE VENT PIPE
FLUE PIPE
6" VENT PIPE TO FAN IN ATTIC
FURNACE DUCT
LINE OF SLAB ON GRADE ABOVE
NORTH
FURNACE
4" VENT PIPE
SUMP WITH COVER AND 4" VENT PIPE
①
②
UP
UNFINISHED
BASEMENT
EXISTING DRAIN & LINE TO SUMP
CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
BEAM
HOLLOW BLOCK WALLS
SEWER
SCALE: 1/8"=1'-0"

Figure 096-1. Basement floor plan for House 096

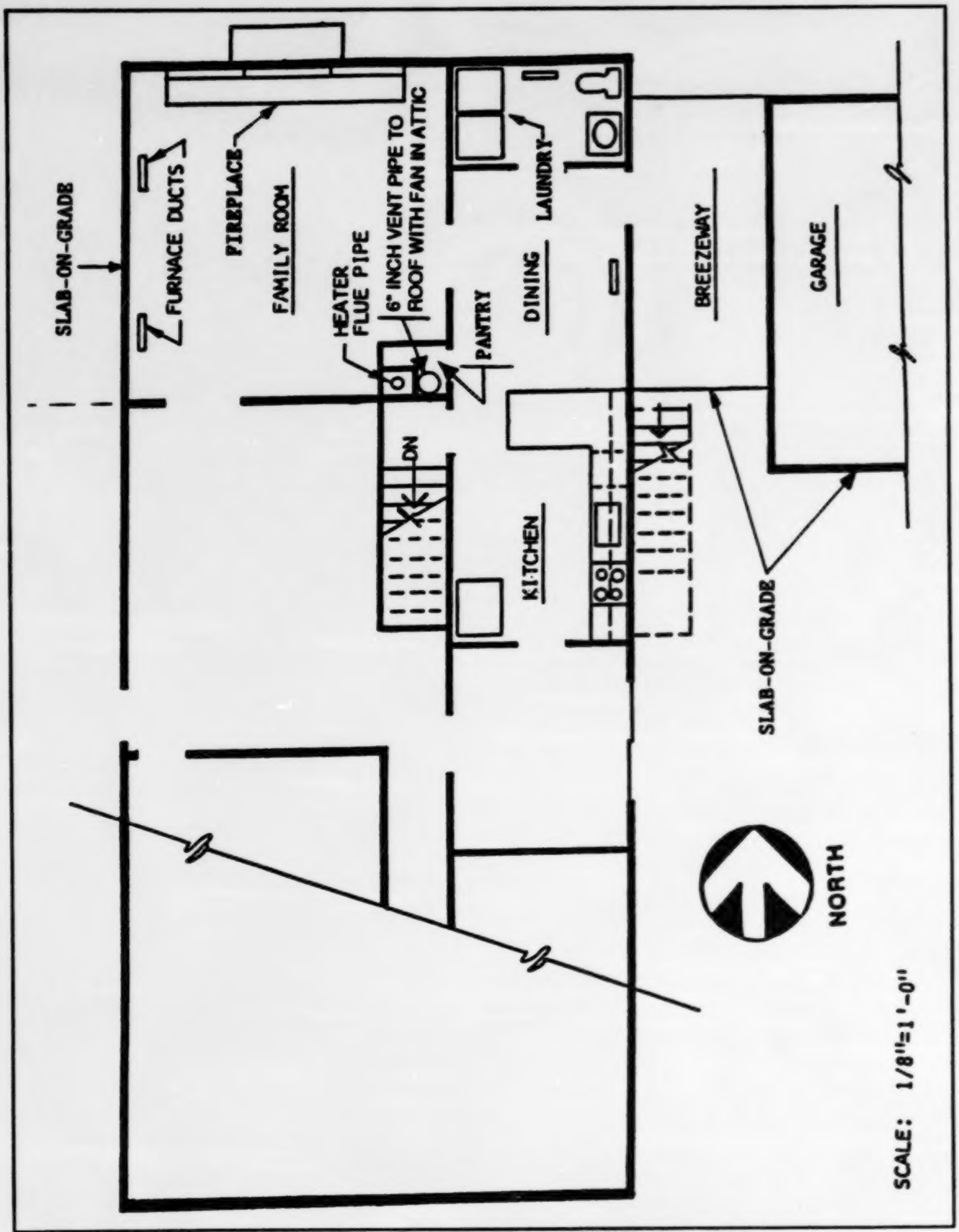

SLAB-ON-GRADE
FURNACE DUCTS
FIREPLACE
FAMILY ROOM
HEATER FLUE PIPE
6" INCH VENT PIPE TO ROOF WITH FAN IN ATTIC
PANTRY
LAUNDRY
DINING
DN
KITCHEN
BREEZEWAY
GARAGE
SLAB-ON-GRADE
NORTH
SCALE: 1/8"=1'-0"

Figure 096-2. Living area floor plan for House 096

HOUSE 106

Basement Measurements	
Pre-mitigation Radon Levels	14.1-58 pCi/L
Stage 1 Post-mitigation Radon Levels	10-15.2 pCi/L
Stage 2 Post-mitigation Radon Levels	7.1-8.6 pCi/L
Stage 3 Post-mitigation Radon Levels	0.1 pCi/L

DESCRIPTION

This two-story house has an unfinished basement with concrete block foundation walls and an adjoining slab-on-grade wing. The house was built in 1983, has wood exterior walls, and is located on a hilltop in a rural area several miles east of Mt. Airy, MD. There is a forced-air electric heating system (heat pump) which the homeowner rarely uses. The primary heat source is a wood-burning stove on the first floor, which exhausts to a centrally located chimney and is not supplied by outside make-up air. There is also a solar heating system. The house has a private well. The basement and slab-on-grade floor plan is shown in Figure 106-1.

The basement is completely below grade. Sill plates rest on top of the block walls; the homeowner reported that fiberglass insulation and aluminum sheet metal had been placed between the blocks and the sill plate during construction. In addition, the top block voids are reportedly mortared shut. The basement walls are penetrated by a well water pipe and a sewer pipe. The basement slab has no cracks. There is an exterior drain tile around the basement that drains to daylight. The floor/wall joint is a perimeter expansion joint, approximately 1/2 inch wide, filled with expansion joint material. There is a sump that has a steel liner a concrete bottom. The attached slab-on-grade (SOG) is divided into three sections by two interior foundation walls that support load-bearing walls. As in the basement, the slab on grade has an expansion joint around the perimeter. According to the homeowner, four inches of crushed stone aggregate is below the basement slab and the SOG. The chimney is constructed of concrete block and brick, and rests on its own footer in the basement. It has four solid clay flues, only two of which are being used.

ACTION - HOUSE 106

Stage 1

The system chosen for this house was passive sub-slab depressurization in the basement, utilizing one of the unused chimney flues as the passive stack. Also, sealing or entry routes in the basement was carried out.

In March 1988, a 6-1/2 inch diameter hole was drilled through the slab near the south basement wall, and a hole was excavated by removing about 10 gallons of soil and aggregate. A 6-inch PVC suction pipe was inserted into the sub-slab access hole, and was extended approximately 4 feet to the chimney. The ash clean out door and frame for the unused southeast chimney flue were removed, and replaced with a plywood cover. The suction pipe was inserted through the plywood flue cover, and sealed around the pipe perimeter. The doors to the other three ash clean-outs were caulked shut, to reduce entry of soil gas into the basement through the chimney block structure.

A wind turbine originally planned for installation above the chimney flue was not used, because the flue gases would have been highly corrosive to a turbine. In addition, significant suction was measured inside the suction pipe without a turbine. On the day the system was installed, the vent pipe suction relative to the basement ranged from 1.25 to 2.50 inches of water, created by high wind speeds and the thermal stack effect. This is an unusually large suction to be created by a passive system.

The basement floor/wall joint, which was filled with fibrous tar-impregnated material, was ground out, partially filled with Sikaflex sealant, and sealed with flowable urethane. In addition, the existing steel sump liner was removed and the sump was filled with concrete.

Suction measurements in the 4-foot length of pipe were repeated one week after installation, on a 55 °F, slightly breezy day. At that time, the suction averaged 0.035 inches of water, which was much lower than the earlier measurement. No flow was detected within the vent pipe. Suctions of 0.005 to 0.007 in. WG were detected under the slab at two test points located at the far basement corners, indicating that most of the sub-slab area was influenced by the passive depressurization system. A suction of 0.010 in. WG was detected in a test hole located close to the suction pipe. Smoke testing indicated that basement air was being drawn into two holes drilled into the basement block wall.

Stage 1 radon levels were measured with Pylon detectors in March 1988. The dining room averaged 10 pCi/L with the passive system off and 5 pCi/L with the passive system on. The basement averaged 21 pCi/L with the passive system off and 10 pCi/L with the passive system on. These data indicated that additional mitigation work would be needed. Grab radon samples were also taken, indicating values of 6.5 pCi/L in the basement, 366 pCi/L below the basement slab, and 4,514 pCi/L inside the suction pipe. Grab samples at other times indicated 149-158 pCi/L under the slab on grade.

To determine whether radon in the basement block wall adjacent to the slab-on-grade (south wall) was contributing to radon in the basement, the south wall and the basement were simultaneously monitored with Pylons over a 4-day period in May 1988. For the most part, radon concentration fluctuations in the block wall correlated with changes in the basement. For this test, the basement averaged 15.2 pCi/L and the block wall averaged 181 pCi/L.

Stage 2

The Pylon tests conducted in May demonstrated that the south wall contained very high radon levels and was probably serving as a radon entry route into the basement. Therefore, in July 1988, this wall was passively depressurized. Two 4-1/2 inch diameter holes were drilled into the cavities inside the south wall, and 4-inch PVC pipe was inserted into the holes. The 4-inch pipe that accessed the two holes was tied into the 6-inch basement SSD pipe at a point directly above the SSD suction point.

Radon levels measured after Stage 2 modifications were lower than Stage 1 values. Alpha-track detectors deployed from August 1988 to November 1988 recorded a radon average of 8.4 pCi/L in the basement. Pylon measurements in the basement in November indicated 7.1 pCi/L. Concentrations in the living area averaged 4.9 pCi/L by the alpha-tracks, and 4.1 pCi/L by the Pylon. Thus, the radon level was still above 4 pCi/L, and mitigation system changes were required.

Stage 3

Activation of the passive sub-slab and wall depressurization system was performed in December 1988. A portion of the 6-inch suction pipe in the basement was removed and replaced with a Fantech Model R-150 (270 cfm) in-line duct fan. A PVC pipe was inserted into the southeast flue from the roof down to the basement and attached to the 6-inch vent pipe. This provided a more effective exhaust stack than the clay flue by itself would have been. A rain hat was attached to the chimney to cover the southeast flue.

A fan control panel was installed in the basement containing a power switch, an on/off light to indicate suction in the pipe, and a rheostat to adjust the fan speed.

With the fan operating, in January 1989, the dining room and basement levels were both 0.0 pCi/L, according to a two-day Pylon measurement.

In May 1989, sub-slab suction measurements were taken with the fan on full power. Suction relative to the basement was 0.241 inches of water in a test hole 2-1/2 feet from the SSD pipe. Suctions in the two far corners of the basement were 0.116 and 0.120 inches of water. These data demonstrated that the active depressurization system was creating suction under most of the basement slab.

The homeowner reported a creosote smell in the house that occurred on calm or rainy days, that could be corrected by lowering the fan speed. This may have been caused by re-entrainment of the gas exhausted from the active vent system flue into the wood stove flue, and back into the house. The homeowner is planning to construct a metal flashing 180 degrees around the active vent system flue to prevent re-entrainment.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 106

The gamma radiation level in the basement averaged 11 uR/hr in June 1987. Freon gas communication tests were conducted in October 1987 by injecting freon gas into a slab hole located in the northeast basement corner. A vacuum was applied to a second slab hole near the south basement wall towards the east side approximately 13 feet away. Freon gas was detected in the vacuum exhaust after one minute, indicating good sub-slab communication.

REMEDIATION SYSTEM - HOUSE 106

Stage	Installation Date	System Description
1	3/88	Passive sub-slab depressurization using the chimney flue as a passive stack; entry route sealing in the basement.
2	7/88	Passive sub-slab and two-point block wall depressurization.
3	12/88	Active sub-slab and two-point block wall depressurization.

TEST DATA - HOUSE 106

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
-	2/88	45	Pre-mitigation	Dining rm (on SOG)	18	12-27
-	"	"	"	Basement	58	33-111
1	3/88	44	Passive off	Dining rm	10	8-15
1	"	45	Passive on	"	5	4-7
1	"	44	Passive off	Basement	21	13-36
1	"	48	Passive on	"	10	7-14
1	5/88	89	Passive on	Basement	15.2	3.9-25.9
1	"	"	"	Inside bsmt wall	181	118-362
2	11/88	93	Passive on	Dining rm	4.1	2.4-5.9
2	"	"	"	Basement	7.1	4.1-12.7
3	1/89	34	Fan off	Basement	10.3	8.4-13.5
3	"	38	Fan on	"	0.1	0.0-0.5
3	1/89	37	Fan off	Dining rm	3.2	1.1-4.8
3	"	44	Fan on	"	0.0	--
3	"	38	Fan off	Basement	7.9	5.2-15.2
3	"	46	Fan on	"	0.0	--

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
2	8/2/88-11/15/88	Dining room (above SOG)	4.1, 5.7
2	"	Basement	8.3, 8.6
2,3	11/15/88-2/16/89	Dining room	1.2, 2.3
2,3	"	Basement	*

* Outside QC goals.

PYLON GRAB SAMPLES - HOUSE 106

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	10/87	Pre-mitigation	Dining room (above SOG)	14.0	0.070
--	"	"	Basement	46.0	0.165
--	"	"	Study	19.1	0.072
--	"	"	Below SOG	149	--
--	"	"	Below bsmt slab	4,908	--
1	3/88	Passive on	Basement	6.5	--
1	"	"	Inside bsmt wall	109	--
1	"	"	Below bsmt slab	366	--
1	"	"	Inside SSD pipe	4,514	--
1	5/88	Passive on	Inside block chimney	35.7	--
1	"	"	Below SOG	158	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
2/87	Pre-mitigation	Basement	19.2	Owner reported
3/87	"	"	44	"
"	"	First floor	10.7	"
8/87	Pre-mitigation	Uncertain	14.1, 14.4	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS - HOUSE 106

Stage	Date	Location*	Suction (inches H_2O)	Flow Rate (cfm)
1	3/88	SSD pipe	1.25 to 2.50	--
1	3/88	SSD pipe	0.035	0
1	"	Test hole 1	0.010	--
1	"	Test hole 2	0.005	--
1	"	Test hole 3	0.007	--
3	5/88	SSD pipe	0.365	55
3	"	East BWD pipe	0.196	38
3	"	West BWD pipe	0.221	72
3	"	Test hole 1	0.241	--
3	"	Test hole 2	0.116	--
3	"	Test hole 3	0.120	--

* Numbers refer to sub-slab test hole locations (see Figure 106-1).

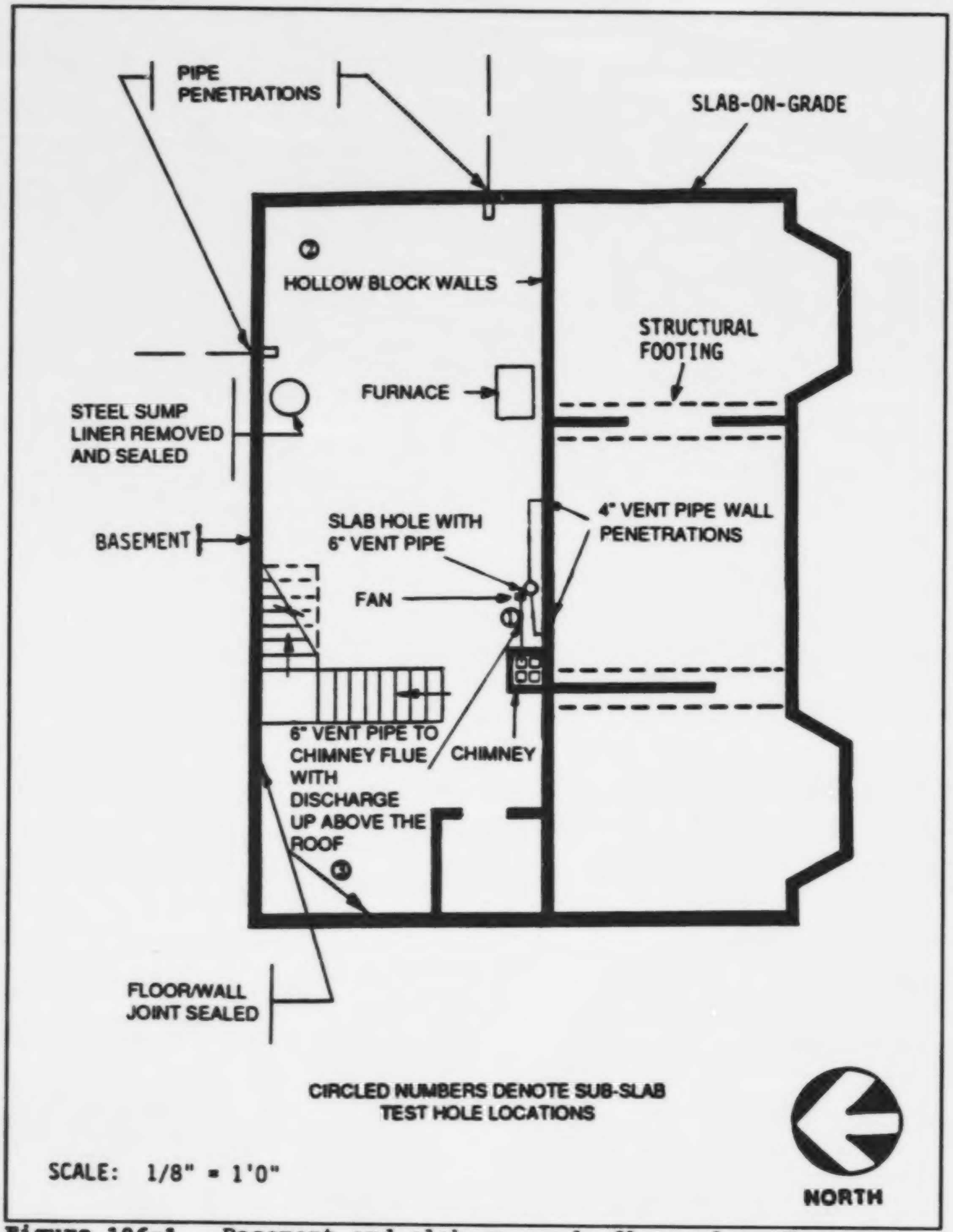

PIPE PENETRATIONS
SLAB-ON-GRADE
HOLLOW BLOCK WALLS
STRUCTURAL FOOTING
FURNACE
STEEL SUMP LINER REMOVED AND SEALED
4" VENT PIPE WALL PENETRATIONS
SLAB HOLE WITH 6" VENT PIPE
BASEMENT
FAN
6" VENT PIPE TO CHIMNEY FLUE WITH DISCHARGE UP ABOVE THE ROOF
CHIMNEY
FLOOR/WALL JOINT SEALED
②
①
③
CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
SCALE: 1/8" = 1'0"
NORTH

Figure 106-1. Basement and slab-on-grade floor plan, House 106

HOUSE 110

Living area measurements	
Pre-mitigation Radon Levels	11.4-31.0 pCi/L
Stage 1 Post-mitigation Radon Levels	0.1-1.2 pCi/L

DESCRIPTION

This one-story slab-on-grade house has hollow-block foundation walls. The house is located on the side of a hill in a rural area a few miles east of Damascus, MD. There is a concrete walkway in the rear of the house, a concrete porch on the east side, and a stone walkway in the front. The original house was built in 1961, and two additions were subsequently made, one in 1973 and the other in 1977; these additions are the current family room and the boiler room. Thus, there are two interior footers subdividing the sub-slab region into three zones. The family room has aluminum siding on the exterior, and all other parts of the house are cinder block with a stucco exterior. The house has an oil-fired boiler/hot water baseboard heating system. In addition, there is a wood stove in the family room that is frequently used in winter for heating. The stove has no make-up air. The house has a private well. The floor plan is shown in Figure 110-1.

A large construction joint runs down the middle of the boiler room slab. The joint between the added boiler room slab and original slab is completely covered with carpet. The joint between the original slab and the added family room slab is partially covered by an interior house wall, and the remainder is located below wooden floor boards. The north and east sides of the family room slab are cracked where the slab overhangs the foundation walls. The remaining slab surfaces could not be inspected for their integrity because they are covered with carpet and tile. There is reportedly bank run gravel beneath the slabs. The family room slab was poured approximately 8 inches above what had originally been a carport slab; fill dirt, gravel, and a polyethylene vapor barrier were placed between the two slabs before the family room slab was poured. The well water and washing machine drain pipes penetrate the boiler room addition slab, and the slab was poured tight around these pipes. Also, the bathroom drain pipes penetrate the original house slab.

Each slab is supported by 8-inch hollow block foundation walls that rest on 8- by 16-inch footers. These footers are largely resting on bedrock, which had to be blasted to allow the footers to be poured. The block foundation walls in the original house and boiler room addition start below grade and continue up to the attic, with a 2- by 8-inch sill plate covering the top voids in the attic. The joists rest on the sill plate. The slabs rest on only a portion of the L-block foundation walls; therefore, the block wall voids located below the slab are connected to the wall voids above the slab. There are three gable vents in the attic and several soffit vents in the roof eaves.

ACTION - HOUSE 110

Prior to their participation in this project, the homeowner hired a radon mitigation contractor who installed a heat recovery ventilator (HRV) in the laundry room. This unit began operation in August 1986 and ran continuously until March 1988. It was designed to remove indoor air from the laundry room and discharge outdoor air into the hallway between the bedrooms. In the winter of 1985/1986, before the HRV was installed, charcoal canister tests indicated that the living room radon concentration was 31 pCi/L. Similar tests during the winter of 1986/1987, with the HRV operating, showed that the radon levels in four test locations ranged from 11.7 pCi/L to 23.0 pCi/L. Operation of the HRV was discontinued once this project started.

Stage 1

Due to the building additions to the original structure and the presence of foundation walls separating the three sub-slab areas from each other, passive sub-slab depressurization would be impractical because passive vent stacks would have been required for each of the three sub-slab areas. In addition, the fact that the house was only one story would reduce the passive suction. Therefore, an active sub-slab depressurization system was chosen, in which each sub-slab area was accessed via the exterior of the structure and manifolded to a common exterior vent stack (see Figure 110-2). Freon gas communication tests conducted on two of the three slabs demonstrated good sub-slab communication under individual slabs, indicating that this approach should be effective.

In March 1988, trenches were excavated along two of the rear walls, approximately 18 inches deep and 2 feet wide. Holes large enough to accommodate 2-inch diameter suction pipes were made horizontally through the foundation walls below slab level, at three locations (one location under each of the 3 slabs). Aggregate was visible below the slabs. According to the homeowner, approximately 4 to 8 inches of aggregate and a vapor barrier are below each slab (tar paper for the original slab and polyethylene for the two additions). The aggregate under the original house slab is "stream wash" and the aggregate below the other 2 slabs is gravel. Perforated, rigid 2-inch PVC suction pipe was installed horizontally through the foundation walls, and extended 2 to 3 feet beneath the three floor slabs. Screens were placed on the pipe ends and the pipes were sealed against the foundation walls.

A 4-inch PVC manifold was connected to each 2-inch pipe. In-line dampers were installed in the manifold between each of the three pipes, to enable balancing of the flow rates. The manifold was extended horizontally along the exterior of the house, to the corner between the utility room and family room where it was routed upward about 6 feet. A Kanalflakt T2 (270 cfm) in-line duct fan was installed at the end of this vertical segment of 4-inch piping, 6 feet above grade. A 6-inch PVC pipe was attached to the exhaust side of fan, and was extended up through the roof eave and topped with a rain hat. The depressurization system was checked for leaks at fittings and coupling joints.

A control panel was installed in the laundry room and was equipped with a power switch, a warning light to indicate that suction was maintained in the vent pipe, and a rheostat to adjust the fan speed. The fan was set at full speed.

The floor slab crack in the boiler room was ground out and sealed. However, the slab cracks in the tiled family room were not sealed because it was believed that active sub-slab depressurization would be sufficient to change the soil gas flow direction at these locations.

Pressure and flow rate measurements indicated a suction of 1.45 in. WG in the piping just before the fan, and a flow of 74 cfm at that point (obtained about equally from the three 2-in. pipes). Also, sub-slab pressure field extension measurements showed a suction of 0.014 in. WG at one test hole through the boiler room slab, and 0.002 to 0.004 in. WG at one test hole through each of the other slabs, remote from the wall that the suction pipes penetrated.

Pylon measurements in April and May all showed radon concentrations below 1 pCi/L. Alpha-track detectors deployed from September 1988 through January 1989 yielded an average radon concentration of 1.1 pCi/L in the family room and 1.0 pCi/L in the laundry room. Alpha-track detectors deployed from January 1989 to April 1989 measured 0.9 pCi/L in the family room and 0.8 pCi/L in the laundry room.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 110

Freon gas communication tests were made on two of the three slabs in October 1987. Freon was injected into a hole drilled through the original house slab and a vacuum drew suction on the opposite side of the slab. Freon was detected in the vacuum exhaust in 2 minutes. A similar test on the family room slab also indicated good sub-slab communication.

REMEDIATION SYSTEM - HOUSE 110

Stage	Date Installed	System Type
1	3/88	Active three-point slab-on-grade depressurization and slab crack sealing.

TEST DATA - HOUSE 110

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
--	1/88	43	Pre-mitigation	Family rm	26.2	11-31
--	3/88	44	Pre-mitigation	Laundry rm	23.8	11-32
1	4/88	45	Fan off	Family rm	24.8	1-34
1	"	39	Fan off	Laundry rm	22.9	13-28
1	"	43	Fan on	"	0.1	0-1
1	5/88	40	Fan off	Family rm	12.6	1.1-32.3
1	"	37	Fan on	"	0.5	0- 3.4
1	"	40	Fan off	Laundry rm	11.6	1.8-28.9
1	"	37	Fan on	"	0.9	0.3- 3.8

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	5/23/88-9/8/88	Family room	0.6, 0.6
1	"	Laundry room	0.6, 0.7
1	9/8/88-1/6/89	Family room	0.9, 1.2
1	"	Laundry room	0.8, 1.2
1	1/6/89-4/6/89	Family room	0.6, 1.1
1	"	Laundry room	0.7, 0.9

PYLON GRAB SAMPLES - HOUSE 110

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	10/87	Pre-mitigation	Living room	38.0	0.129
--	"	"	Office	31	0.094
--	"	"	Boiler room	36	--
--	"	"	Bathroom	31	--
--	"	"	Laundry room	29.3	0.105
--	"	"	Pipe into slab (laundry room)	179	--
1	4/88	Fan on	Family room	0.2	--
1	"	"	Boiler room	0.0	--
1	"	"	SSD manifold	45.3	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
Winter 1985/86	Prior to HRV	Living room	31.0, 30.9	Owner reported
Winter 1986/87	"	Living room, dining room, bathroom, & bedroom	11.7-23.0	"
8/87	With HRV operating	Dining room	11.4, 12.7	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Test Condition	Location*	Suction (inches H_2O)	Flow Rate (cfm)
1	4/88	Fan on	Slab 1 SSD pipe	1.32	20
1	"	"	Slabs 1 & 2	1.36	52
1	"	"	Slabs 1, 2 & 3	1.45	73
1	"	"	Test hole 1	0.004	--
1	"	"	Test hole 2	0.002	--
1	"	"	Test hole 3	0.014	--

* Slab 1 is under family room addition, slab 2 is under living room, and slab 3 is under boiler room addition (see Figure 110-1). Sub-slab test hole locations also shown in figure.

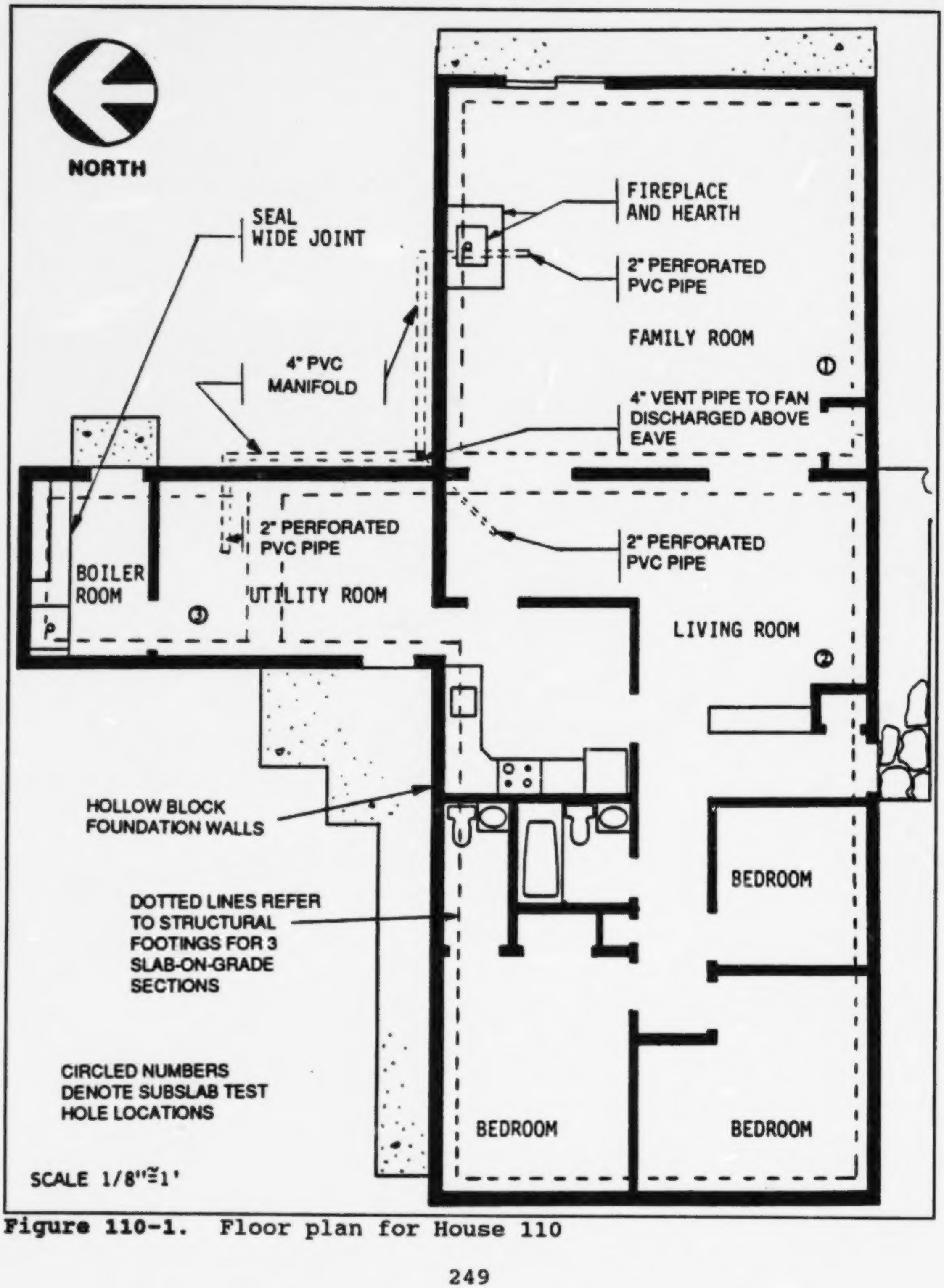

NORTH
SEAL
WIDE JOINT
FIREPLACE
AND HEARTH
2" PERFORATED
PVC PIPE
P
FAMILY ROOM
①
4" PVC
MANIFOLD
4" VENT PIPE TO FAN
DISCHARGED ABOVE
EAVE
2" PERFORATED
PVC PIPE
BOILER
ROOM
P
③
UTILITY ROOM
2" PERFORATED
PVC PIPE
LIVING ROOM
②
HOLLOW BLOCK
FOUNDATION WALLS
BEDROOM
DOTTED LINES REFER
TO STRUCTURAL
FOOTINGS FOR 3
SLAB-ON-GRADE
SECTIONS
CIRCLED NUMBERS
DENOTE SUBSLAB TEST
HOLE LOCATIONS
BEDROOM
BEDROOM
SCALE 1/8"≅1'

Figure 110-1. Floor plan for House 110

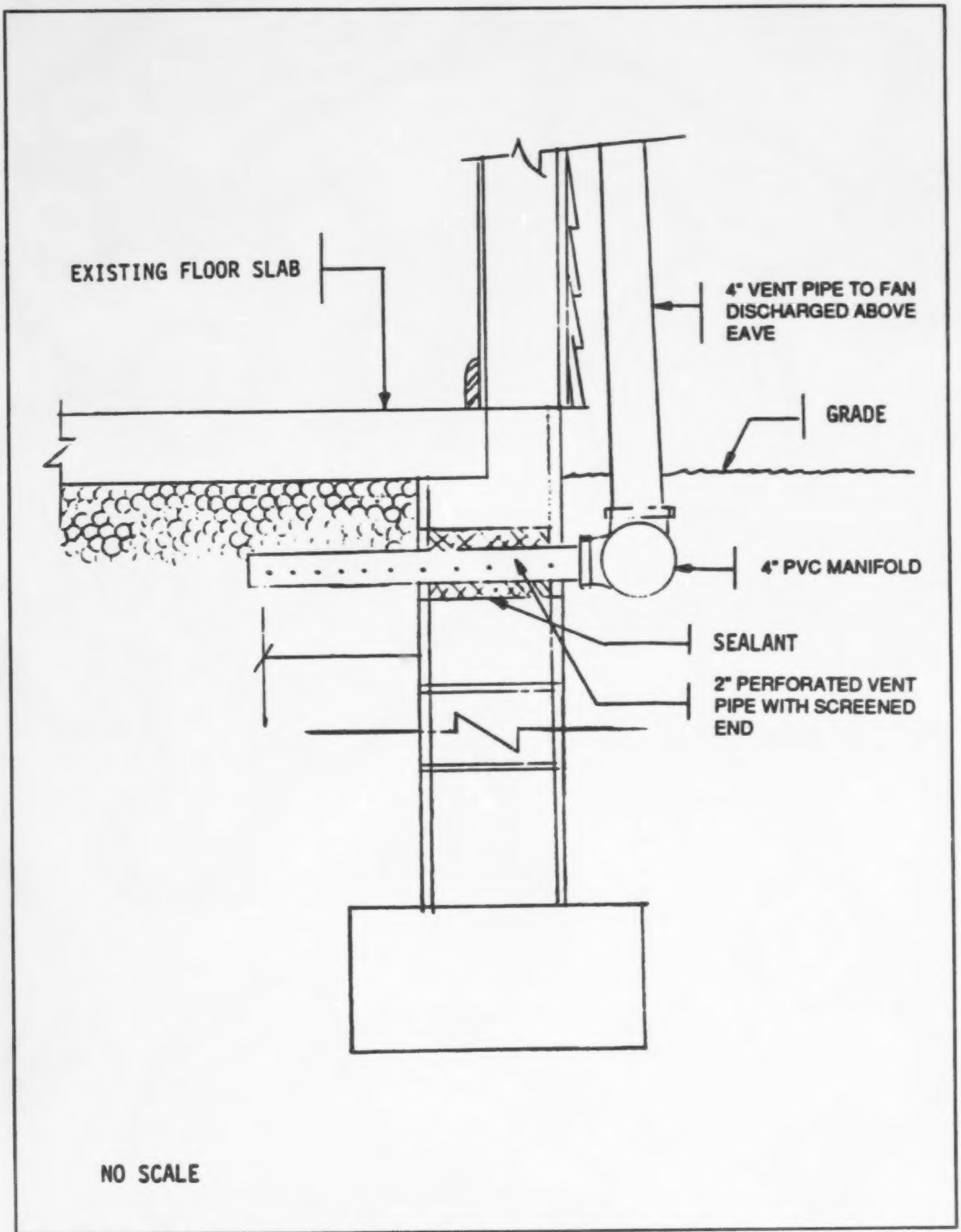

EXISTING FLOOR SLAB
4" VENT PIPE TO FAN DISCHARGED ABOVE EAVE
GRADE
4" PVC MANIFOLD
SEALANT
2" PERFORATED VENT PIPE WITH SCREENED END
NO SCALE

Figure 110-2. Exterior penetration into sub-slab in House 110

HOUSE 126

Basement Measurements	
Pre-mitigation Radon Levels	5.8-55.8 pCi/L
Stage 1 Post-mitigation Radon Levels	0.5-1.9 pCi/L

DESCRIPTION

This one-story house had a basement and, originally, a crawl space, with concrete block foundation walls. There is also an attached slab-on-grade porch. Prior to the initiation of mitigation work, the owner converted the crawl space into a basement addition, which is separated from the original basement by a frame wall and doorway. The house was built in 1959, has a stone exterior, and is located in a hilly and rural area several miles southwest of Parkton, MD. The house has hot water baseboard heating with an oil furnace and a coal/wood-fired boiler. Neither furnace is supplied with outside make-up air. There is a fireplace in the basement family room that the homeowner rarely uses. The house is served by a private well. The floor plan is shown in Figure 126-1.

The hollow block foundation walls have solid cap blocks. The original crawl space foundation walls are 4 feet tall, and rest on footers located approximately 4 feet above the basement slab. There is a hollow concrete block stem wall (5 feet tall) between the basement and the original crawl space that has open top voids. A sill plate covers the open top voids on half of the stem wall. The north room in the original basement is an unfinished workroom, and the south room is a family room with paneling, drywall, and carpeting. The workroom walls are cracked and are penetrated by the two furnace flues and an abandoned flue. Part of the workroom slab is tiled, and the remainder is painted and has some cracks. The workroom slab has a small layer of stone aggregate below. There is an open sump and no perimeter drain tile. An exterior stairwell has a floor drain that empties to the sump. The south wall of the original crawl space is penetrated by a 4-inch sewer pipe, and the west crawl space wall has a small window.

Prior to the beginning of mitigation work in April 1988, the homeowner excavated the crawl space dirt to approximately three feet below the basement slab. Three poured concrete walls, five feet in height, were poured below the three exterior crawl space wall footers. See Figure 126-2. The cracks between the new poured concrete walls and the existing crawl-space footers were sealed with a water resistant caulk. The existing hollow block walls and the new poured concrete walls were painted with cement sealant. A trench was dug in the crawl space dirt around the entire perimeter, and 4-inch perforated PVC pipe was placed inside and buried in aggregate. The earthen crawl-space floor was then covered with approximately 4 inches of gravel; a plastic vapor barrier, then 2 inches of sand, were placed over the gravel, and an 8-inch-thick concrete slab was poured. At the east side of the crawl space, the two ends of the 4-inch perforated pipe were passed up through the new slab and connected together, completing the loop. An additional section of 4-inch perforated pipe was placed along the three new poured concrete walls approximately 3 feet above the slab, and capped at both ends. This above-slab section of perforated pipe was intended to be covered by a frame wall, acting as a plenum wall depressur-ization system. As shown in Figure 126-2, the pipe was enclosed in a plastic sheet extended from the floor/wall joint to the top of the three poured concrete walls.

ACTION - HOUSE 126

Stage 1

The mitigation system implemented in this house is an active sub-slab depressurization system in the original basement, in conjunction with an active drain tile depressurization system in the new basement addition. The system in the new addition might also be looked upon as a crawl-space sub-liner depressurization system in which the liner is a concrete slab. Both segments were treated because the stem wall footings were expected to interrupt the sub-slab suction field between the original basement and the addition.

In April 1988, a 4-inch PVC ventilation pipe was connected to both the sub-slab and above-slab perforated pipes in the addition, and routed through what had been the crawl space window. Outside, the pipe was expanded to 6 inches in diameter, and was extended upward above the roof line, and topped with a rain hat. A Kanalflakt Model T2 (270 cfm) in-line duct fan was installed in the 6-inch stack.

A 4-1/2 inch diameter hole was drilled through the slab of the original basement, in the workroom near the east wall. Ten gallons of stone and dirt were removed through this hole. A 4-inch PVC suction pipe was installed in the hole, and routed to the northeast basement corner. The basement SSD pipe was to be extended up to the roof inside the existing chimney flue in the northeast basement corner. However, during installation, it was not possible to penetrate the flue liner without damaging it. Therefore, the basement suction pipe was routed through the north basement foundation wall. Outdoors, the pipe was expanded to 6 inches in diameter, and extended up the house exterior to above the roof line. A concrete base was poured underneath this stack to support it. A Kanalflakt Model T2 (270 cfm) in-line duct fan was installed in the 6-inch stack, and a rain hat was placed on top. The floor/wall joint in the workroom was ground out and sealed. The sump and the exterior stairwell drain were filled with concrete. Also, the north basement wall was painted with a cement waterproofing paint that appeared to effectively seal the porous block wall.

A control panel was installed for both the SSD and the DTD system fan. Each control panel contains a power switch, an on/off light to indicate suction in the vent pipe, and a rheostat to adjust the fan speed.

Pylon measurements taken in April 1988 were 55.8 pCi/L in the new addition with both fans off; this decreased to 1.2 pCi/L when the two fans were turned on. Pylon data in the original basement is not available for this test period.

Suction and flow rates were measured in April 1988 for the DTD system in the addition. Suctions of 0.005 to 0.026 in. WG were measured through 4 sub-slab test holes within 20 feet of where the suction pipe penetrated up through the slab. Suction in the DTD pipe just above the slab was 0.055 in. WG. These data showed that a major portion of the new slab was being influenced. The flow rate in the DTD pipe, at a point prior to its connection with the elevated perforated pipe, was 44 cfm; downstream of that connection, the flow rate in the pipe was 183 cfm. Therefore, the elevated perforated pipe was drawing 139 cfm of crawl space air into the depressurization system. This indicated that most of the air was entering the DTD system through the above slab perforated pipe. To balance the flow rates, recommendations were made to install dampers in the above-slab perforated pipe.

Suction and flow rate measurements for the basement SSD system were also taken. Suctions of 0.003 to 0.21 in. WG were detected at 4 sub-slab test holes in the workroom located within 4 feet of the sub-slab suction hole. However, no suction was detected in a fifth test hole located 8 feet away. It would appear that not all of the basement slab was being influenced by the depressurization system. The SSD pipe flow rate was 3 cubic feet per minute (cfm) and the suction was 1.85 inches of water, confirming that communication under the original basement was poor, at least at that point. Smoke tests indicated that no flow existed in the sealed sump.

Additional Pylon tests were made in May 1988 to demonstrate the relative affects of each of the two depressurization systems on the indoor radon concentrations. With both fans off, the basement family room level averaged 5.8 pCi/L, and the level in the addition averaged 30.7 pCi/L (an impressive gradient). With only the workroom SSD fan on, the basement family room level actually increased to 13.5 pCi/L, and the level in the addition increased to 49.8 pCi/L. With only the addition DTD fan on, the basement family room level was reduced to 0.7 pCi/L, and the addition was reduced to 1.0 pCi/L. With both fans on, the basement family room level was 0.5 pCi/L and the crawl space was 0.7 pCi/L. The data demonstrated that the active depressurization system was very effective. The data also demonstrated that the DTD system seemed to be the major contributor to the radon reductions in the structure. The limited data indicated that the basement sub-slab depressurization system had very little effect, if any, in reducing radon levels.

In July 1988, the perforated pipe located above the new slab was partially dampered off to increase suction on the perforated pipe located below the slab. This was done based on earlier flow rate tests.

In October 1988, the homeowner was instructed to construct a wooden plenum wall to enclose the above-slab perforated pipe in the addition. This was completed to improve suction on the new poured concrete walls and wall/floor joint.

Once all modifications had been completed, the mitigation system consisted of basement sub-slab depressurization, interior drain tile depressurization under the new slab, and plenum wall depressurization.

Alpha-track detectors were deployed from January 1989 to April 1989, after the dampering of the above-slab pipe and after construction of the plenum wall. The kitchen radon level was 0.6 pCi/L and the crawl space level was 0.7 pCi/L, demonstrating that radon levels continued to be low.

PRE-MITIGATION DIAGNOSTIC TESTING

The gamma radiation was 12 uR/hr inside the house in June 1987.

REMEDIATION SYSTEM - HOUSE 126

Stage	Installation Date	System Description
1	4/88	Active sub-slab depressurization, active drain tile depressurization, and entry route sealing.

TEST DATA - HOUSE 126

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
1	4/88	40	Both fans off	Addition	55.8	23.3-80.4
1	"	39	Both fans on	"	1.2	0.6-1.6
1	5/88	26	Both fans off	"	30.7	18.0-48.6
1	"	24	Fan 1 on, Fan 2 off*	"	49.8	26.2-82.3
1	"	13	Fan 1 off, Fan 2 on*	"	1.0	0.4-1.4
1	"	18	Both fans on	"	0.7	0.1-1.2
1	"	27	Both fans off	Basement family rm	5.8	0.6-13.6
1	"	24	Fan 1 on, Fan 2 off*	"	13.5	6.9-23.6
1	"	13	Fan 1 off, Fan 2 on*	"	0.7	0.1-1.2
1	"	18	Both fans on	"	0.5	0.1-1.2

* Fan 1 is on the SSD system in the original basement, Fan 2 is on the DTD system in the new addition.

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Test Condition	Location	Reported Rn for each Detector (pCi/L)
1	5/23/88-9/8/88	Both fans on	Kitchen	1.1, 1.1
1	"	"	Bsmt addition	1.2, 1.9
1	9/8/88-1/10/89	"	Kitchen	0.7, 1.0
1	"	"	Bsmt addition	1.4, 1.9
1	1/10/89-4/13/89	"	Kitchen	0.5, 0.7
1	"	"	Bsmt addition	0.6, 0.7

PYLON GRAB SAMPLES - HOUSE 126

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	6/87	Pre-mitigation	Bedroom	38	0.21
--	"	"	Family room (original bsmt)	104	0.50
--	"	"	Inside north bsmt. wall	250	--
--	10/87	House windows open	Workroom (original bsmt)	57	0.129
--	"	"	Crawl space (bef. converted)	83	--
--	"	"	Inside bsmt wall	34	--
--	"	"	Below bsmt slab	653	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
11/86	Pre-mitigation	Basement family room	44.7	Owner reported
8/87	Pre-mitigation	Basement	44.9, 46.2	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Location	Suction (inches H_2O)	Flow Rate (cfm)
1	4/88	SSD pipe	1.850	3
1	"	8" from SSD pipe*	0.210	--
1	"	20" from SSD pipe*	0.013	--
1	"	32" from SSD pipe*	0.006	--
1	"	44" from SSD pipe*	0.003	--
1	"	96" from SSD pipe*	0.000	--
1	"	DTD pipe**	0.055	44
1	"	DTD pipe***	--	183
1	"	3' from DTD pipe****	0.026	--
1	"	5' from DTD pipe****	0.023	--
1	"	12' from DTD pipe****	0.014	--
1	"	20' from DTD pipe****	0.005	--

* Sub-slab test hole on original basement slab.
** At a point including flow only from underneath the new slab.
*** At a point including both sub-slab and above-slab flows.
**** Sub-slab test hole on new slab.
NOTE: Tests were made with both fans on.

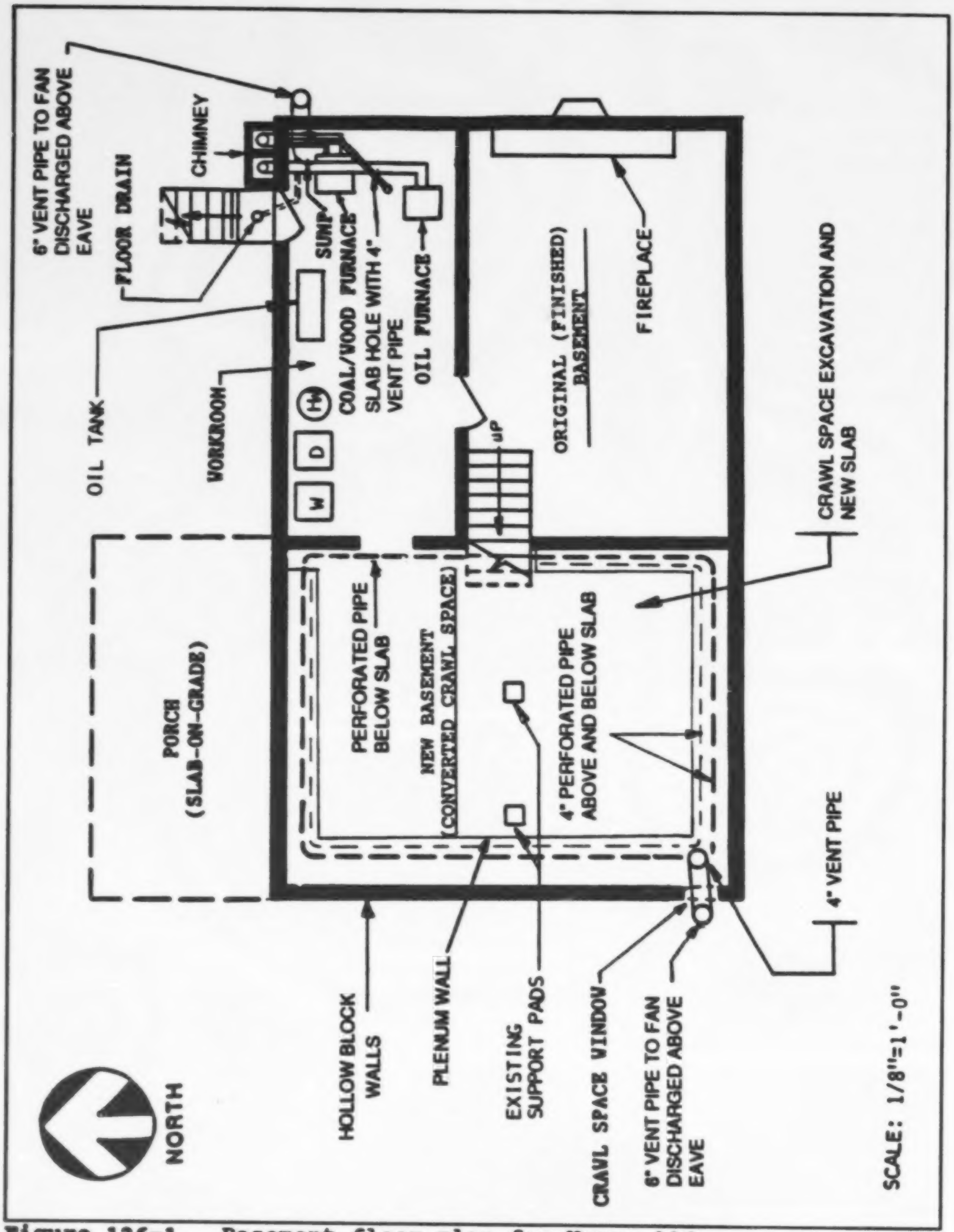

6" VENT PIPE TO FAN DISCHARGED ABOVE EAVE
CHIMNEY
FLOOR DRAIN
OIL TANK
WORKROOM
W
D
HW
SUMP
COAL/WOOD FURNACE
SLAB HOLE WITH 4" VENT PIPE
OIL FURNACE
UP
ORIGINAL (FINISHED) BASEMENT
FIREPLACE
CRAWL SPACE EXCAVATION AND NEW SLAB
PORCH (SLAB-ON-GRADE)
PERFORATED PIPE BELOW SLAB
NEW BASEMENT (CONVERTED CRAWL SPACE)
4" PERFORATED PIPE ABOVE AND BELOW SLAB
4" VENT PIPE
NORTH
HOLLOW BLOCK WALLS
PLENUM WALL
EXISTING SUPPORT PADS
CRAWL SPACE WINDOW
6" VENT PIPE TO FAN DISCHARGED ABOVE EAVE
SCALE: 1/8"=1'-0"

Figure 126-1. Basement floor plan for House 126

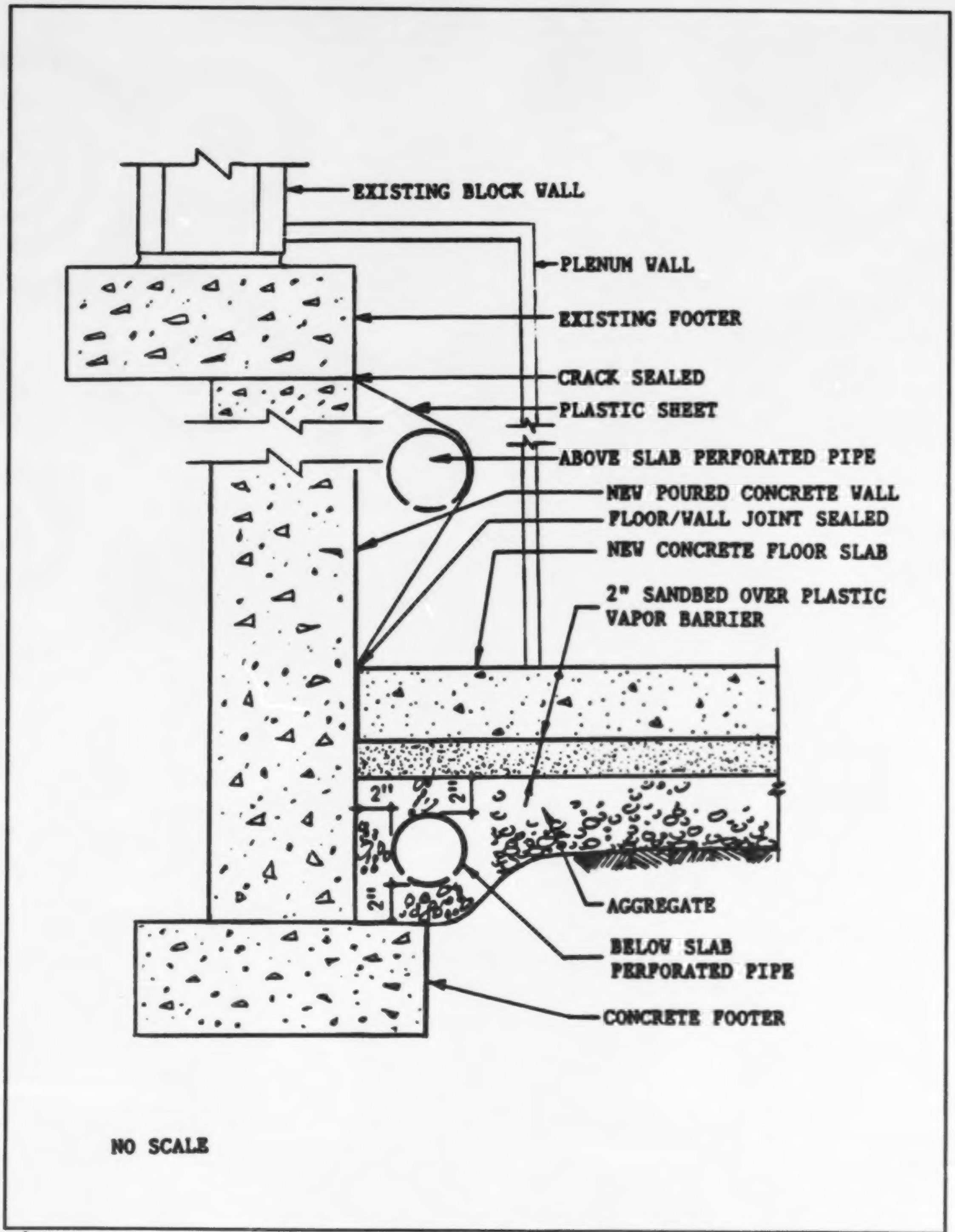

EXISTING BLOCK WALL
PLENUM WALL
EXISTING FOOTER
CRACK SEALED
PLASTIC SHEET
ABOVE SLAB PERFORATED PIPE
NEW POURED CONCRETE WALL
FLOOR/WALL JOINT SEALED
NEW CONCRETE FLOOR SLAB
2" SANDBED OVER PLASTIC VAPOR BARRIER
2"
2"
2"
2"
AGGREGATE
BELOW SLAB PERFORATED PIPE
CONCRETE FOOTER
NO SCALE

Figure 126-2. Placement of perforated pipes in basement addition

HOUSE 143

Basement Measurements	
Pre-mitigation Radon Levels	52.6-71 pCi/L
Stage 1 Post-mitigation Radon Levels	1.1-3.5 pCi/L

DESCRIPTION

This two-story house has an unfinished basement with hollow block foundation walls. There is an attached slab-on-grade garage. An exterior drain tile surrounds three-quarters of the basement. The house was built in 1982, has plywood siding, and is located in a hilly rural area a few miles south of Mt. Airy, MD. There is a forced-air electric heat pump system that is supplemented with a wood burning basement furnace. The house has a private well. The basement floor plan is shown in Figure 143-1.

The walk-out basement is below grade in the front; the ground slopes such that the basement is at grade in the back. The hollow block basement walls have open top voids. There are sill plates resting on top of the basement walls, with insulation and a plastic sheet under the sill plate providing a partial seal. The block walls have been filled with concrete, with rebar approximately every 8 feet. The basement walls are painted with latex paint, have no cracks, and are penetrated by a 4-inch sewer pipe, a well water pipe, an A/C condensate line, and a wood stove flue. The basement slab is sealed with polyurethane, and has one crack near the furnace. There is no sub-slab aggregate, but, according to the homeowner, the sub-slab is very rocky with soft shale. The slab is penetrated by two 3-inch hollow support posts. The width of the basement floor/wall joint ranges from a hairline crack to 1/16 inch. No basement sump hole exists, but there is an exterior drain tile that drains above grade at two locations. The basement floor drain has been sealed, and the cold air return ducts have been taped by the homeowner.

ACTION - HOUSE 143

A heat recovery ventilator (HRV) was installed in the basement by the homeowner in early 1987, prior to their involvement in this project. According to the homeowner, charcoal canister tests made by the State of Maryland indicated that radon levels were reduced approximately 50 percent by the HRV. During Pylon and charcoal canister tests made for this project, the HRV was turned off. Operation of the HRV was discontinued once the Stage 1 system had been installed.

Stage 1

The mitigation action chosen for this house was an active sub-slab depressurization system. This choice was made in view of: a) the high radon levels in the house; and b) the poor sub-slab communication indicated by pre-mitigation diagnostic measurements (as well as the reported lack of aggregate).

In January 1988, two 4-1/2 inch diameter sub-slab access holes were drilled through the slab, 21 inches apart. A 2-foot by 2-foot by 20-inch deep hole was excavated under the slab through these two holes, without having to jackhammer a large hole in the slab. Rocks and dirt were present beneath the slab, but no aggregate was observed. The rocks needed to be broken up to be removed from the holes. A 4-inch diameter PVC suction pipe was installed in one of the slab holes, and sealed with flowable urethane caulk in a channel chipped in the concrete around the pipe perimeter. The second hole was sealed with non-shrink grout. The hole that had been excavated under the slab was left as an unfilled void. An unused floor drain was caulked shut, but no other sealing was attempted. The suction pipe was extended up from the slab hole to the basement ceiling, then routed horizontally to the north basement wall, where it penetrated the band joist at a point underneath an exterior deck. Outside, the exhaust pipe was extended about 6 feet straight out away from the house, underneath the deck. A 90 degree elbow was attached to the vent pipe end to direct the air flow down, and a screen was placed inside the elbow. A Kanalflakt Model K4-XL (179 cfm) in-line duct fan was installed on a horizontal piping run within the basement and the fan speed was set to high.

A fan control panel was installed in the basement, containing a power switch, an on/off light to indicate that suction is maintained in the pipe, and a rheostat to adjust the fan speed.

Flow rates were measured inside the exterior drain tiles, at each of the two above-grade discharges, with the SSD system operating. The south discharge pipe flow rate was 19 cubic feet per minute into the tiles, and the north pipe was 24 cfm into the tiles. This showed that the sub-slab depressurization system was sucking outdoor air into the system via the drain tiles, which might reduce the system's ability to extend a suction field underneath the entire slab.

Pylon measurements in January 1988 with the active system operating indicated radon levels of 1.5 pCi/L in the living room and 1.6 pCi/L in the basement. Measurements with the two above-grade discharges closed gave 1.3 pCi/L in the living room and 1.6 pCi/L in the basement. This indicated that closing the drain tile discharges did not appreciably decrease the radon levels.

Average radon levels measured from February 1988 to May 1988 using alpha-track detectors, were 1.3 pCi/L in the living room and 1.7 pCi/L in the basement. These values represent large reductions in radon levels, since the pre-mitigation Pylon measured levels were

36.8 pCi/L in the living room and 71 pCi/L in the basement.

Sub-slab pressure field extension measurements were made, as well as suction and flow rate measurements in the SSD piping. With the fan operating at full speed, a suction of 1.25 in. WG and a flow of 60 cfm were measured in the piping. Sub-slab suctions of 0.006 to 1.07 in. WG were found in three test holes in the south and southeast portions of the slab; however, in five other test holes in other parts of the slab, no suction could be measured.

With the fan at low speed, piping suction and flow fell to 1.05 in. WG and 53 cfm. Suctions under the slab at the three test holes in the south and southeast parts of the slab fell to 0.001 to 0.095 in. WG.

In July, the in-line duct fan was removed from the basement and re-installed within the outside horizontal vent pipe below the deck. This action was taken to prevent concentrated radon gas inside the piping from leaking into the basement in the event that the seals connecting the fan to the PVC pipe deteriorate or leak.

The average basement radon level was measured from December 1988 to March 1989 using alpha-track detectors to be 3.4 pCi/L. This indicated an increase over the earlier 1.7 pCi/L measurement that had been obtained before the fan was moved outdoors. This apparent increase was probably due to the cooler weather during this second measurement.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 143

Freon gas communication tests made in July 1987 indicated poor sub-slab communication. Freon gas was injected into a hole drilled near the furnace and, after 30 minutes, was not detected in a second hole drilled approximately 30 feet away near the south wall.

Freon was also not detected in a third test hole located approximately 25 feet away near the east side of the north wall. However, when suction was applied to the exterior drain tile, freon was detected in the vacuum exhaust.

REMEDIATION SYSTEM - HOUSE 143

Stage	Installation Date	System Description
1	1/88	Active sub-slab depressurization.
1A	7/88	Fan moved to exterior of house.

TEST DATA - HOUSE 143

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
--	11/87	43	Pre-mit.*	Living rm	36.8	17-58
--	"	46	"	Basement	71	33-89
1	1/88	13	Fan off	Living rm	27.3	17-31
1	"	27	Fan on	"	1.5	1-3
1	"	24	Fan on**	"	1.3	1-3
1	"	14	Fan off	Basement	52.6	48-58
1	"	31	Fan on	"	1.6	1-3
1	"	25	Fan on**	"	1.6	1-2
1A	7/88	44	Fan off	Living rm	1.2	2.9-0.7
1A	"	44	Fan on	"	1.3	0.6-2.6
1A	"	43	Fan off	Basement	1.2	0.5-2.2
1A	"	44	Fan on	"	1.1	0.7-1.7

* Basement window open 1/2 inch during test.
** Two exterior drain tile above-grade discharges plugged.

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Location	Reported Rn for each Detector (pCi/L)
1	2/5/88-5/4/88	Living room	1.1, 1.4
1	"	Basement	1.6, 1.7
1,1A	5/4/88-8/9/88	Living room	1.4, 1.6
1,1A	"	Basement	1.6, 1.7
1A	8/9/88-12/7/88	Living room	2.7, 2.8
1A	"	Basement	*
1A	12/7/88-3/15/89	Living room	2.3
1A	"	Basement	3.3, 3.5

* Data outside QC goals.

PYLON GRAB SAMPLES - HOUSE 143

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	7/87	Pre-mitigation	Family room	3	0.005
--	"	"	NW Basement	3	0.003
--	"	"	West wall	2	--
--	"	"	South wall	14	--
--	"	"	Drain tile	280	--
--	10/87	"	Sub-slab	2480	--
1	3/88	Fan on	Basement	2.3	--
1	"	"	Inside SSD pipe	287	--
1	"	"	Inside wall	15	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
<2/86	Pre-mitigation	Family room	57.2	Owner reported
2/86	"	"	46.8	"
8/87	Pre-mitigation	Uncertain	41.3, 45.4	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Location*	Suction (in. H_2O)		Flow Rate (cfm)	
			Fan low	Fan high	Fan low	Fan high
1	3/88	In SSD pipe	1.05	1.25	53	60
1	"	Test hole 1	0.095	1.07	--	--
1	"	Test hole 2	0.008	0.022	--	--
1	"	Test hole 3	0.001	0.006	--	--
1	"	Test hole 4	**	**	--	--
1	"	Test hole 5	**	**	--	--
1	"	Test hole 6	**	**	--	--
1	"	Test hole 7	**	**	--	--
1	"	Test hole 8	**	**	--	--
1A	7/88	In SSD pipe	--	--	48	56

* Numbers refer to sub-slab test hole location (see Figure 143-1).

** Not detected.

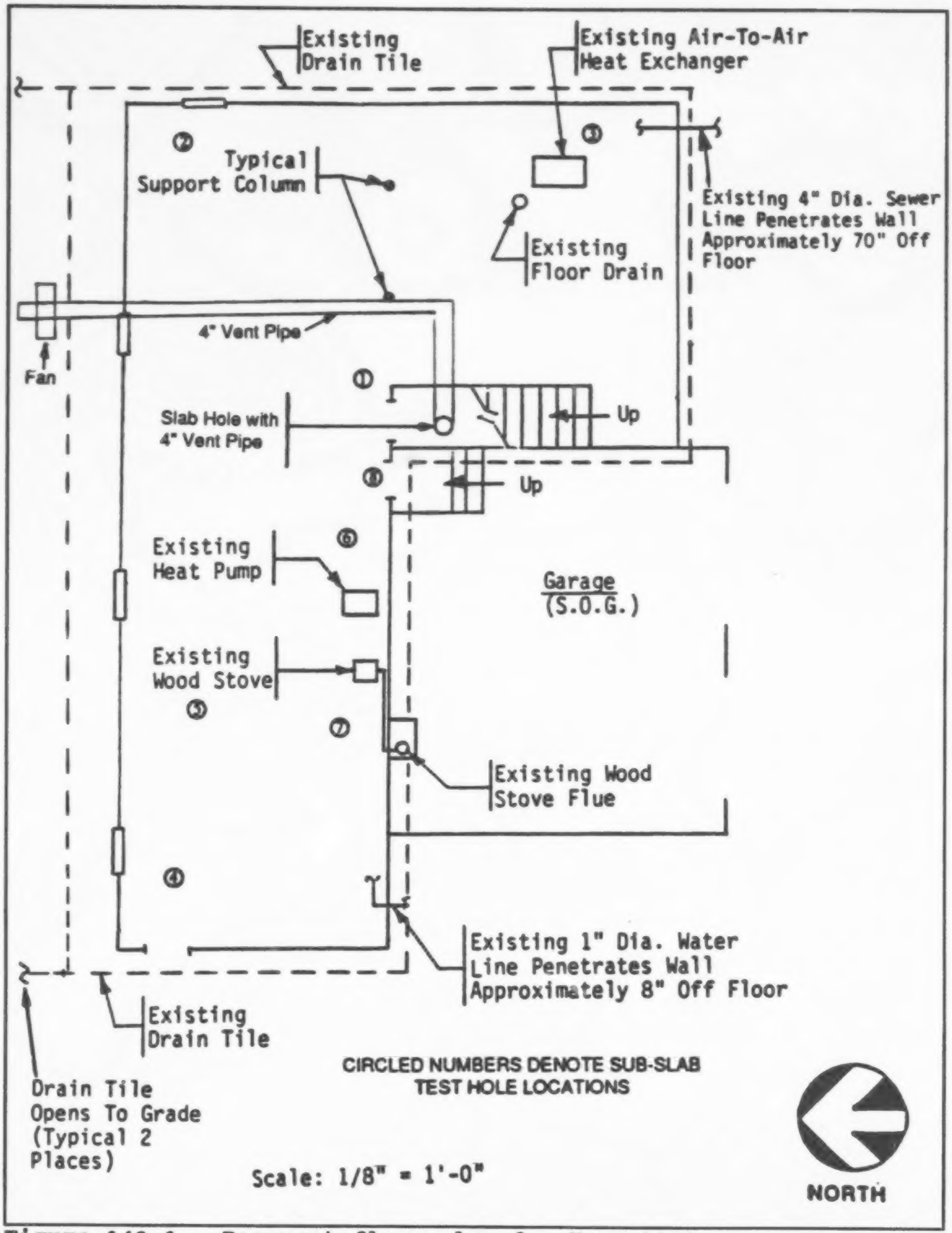

Existing Drain Tile
Existing Air-To-Air Heat Exchanger
②
③
Typical Support Column
Existing 4" Dia. Sewer Line Penetrates Wall Approximately 70" Off Floor
Existing Floor Drain
4" Vent Pipe
Fan
①
Slab Hole with 4" Vent Pipe
Up
⑧
Up
⑥
Existing Heat Pump
Garage (S.O.G.)
Existing Wood Stove
⑤
⑦
Existing Wood Stove Flue
④
Existing 1" Dia. Water Line Penetrates Wall Approximately 8" Off Floor
Existing Drain Tile
Drain Tile Opens To Grade (Typical 2 Places)
CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
Scale: 1/8" = 1'-0"
NORTH

Figure 143-1. Basement floor plan for House 143

HOUSE 163

Basement Measurements	
Pre-mitigation Radon Levels	19.1-31.0 pCi/L
Stage 1 Post-mitigation Radon Levels	
- fan at full power	0.8 pCi/L
- fan at reduced power	0.6-4.8 pCi/L

DESCRIPTION

This one-story house has an unfinished basement with an adjoining crawl space, with hollow block foundation walls. There is also a slab-on-grade patio beside the house. The house was built in 1984, has aluminum siding, and is located in a hilly rural area a few miles west of Westminster, MD. The house has forced-air electric heating. It is served by a private well. The floor plan is shown in Figure 163-1).

The hollow block walls in the basement are located completely below grade, and are penetrated by the well water pipe and the sewer line. The top voids of the 12-inch-wide block walls are partially capped with 8-inch-wide cap blocks. The remaining open space is sealed with mortar. The floor/wall joint is tight, and the basement slab has a few major cracks. There is a basement exterior stairwell drain that empties to a dry well below. The owner, who built this house, reported that no aggregate was placed under the slab during construction. A complete drain tile loop exists, but no sump is present. A small opening, without a door, leads from the basement into the crawl space; air ducts pass through this access way. The crawl space has two foundation vents. There is a vapor barrier covering the soil in the crawl space; this plastic sheeting was not sealed to the foundation walls.

ACTION - HOUSE 163

Stage 1

Since pre-mitigation tests using freon gas indicated poor sub-slab communication, and since the radon level in the basement was fairly elevated according to the Pylon measurements (31 pCi/L), it was decided that a passive soil depressurization system probably would not provide sufficient reductions. Therefore, an active sub-slab and sub-liner depressurization system was installed, along with sealing of cracks in the basement slab.

In March 1988, a 2-foot by 2-foot hole was cut into the west end of the basement slab. To reduce pressure losses in the depressurization system, eight cubic feet of hard-packed soil and stone were excavated. The hole was then filled (to the underside of the slab) with three-quarter inch washed rock, and a 4-inch-diameter SSD pipe was inserted. The opening was repaved with new concrete; a channel was tooled into the new concrete around the pipe perimeter and around the perimeter of the 2' X 2' patch, and these seams were sealed with flowable urethane caulk. The suction pipe was extended up to the basement ceiling, then horizontally over to the northeast corner. A damper was installed in the SSD pipe to permit adjustment of the flow rate in the pipe.

Flexible 4-inch perforated pipe was laid in a serpentine pattern on the floor of the crawl space. The floor was then covered with heavy-duty 20-mil polyethylene sheeting, as illustrated in Figure 163-2, similar to the material used in House 074. The membrane was sealed to the four crawl space walls by sandwiching the end of the plastic between a furring strip and a bead of caulk. Seams between sheets of plastic were sealed using three parallel beads of caulk between the ends of the sheets. The perforated pipe was connected to 4-inch PVC pipe which ran out the crawl space and was tied into the SSD system in the basement. A damper was placed in this SLD vent pipe to permit adjustment of the flow rate in the pipe.

A Kanalflakt T2 in-line duct fan (270 cfm) was installed horizontally in the basement, in the single exhaust pipe from the combined SSD plus SLD system. This fan was set on high speed. A condensate drain line was installed from the bottom of the fan housing to the interior of the block wall. The piping penetrated the basement band joist, then was directed up outside the house through the roof eave, and was topped with a rain hat.

A fan control panel was installed in the basement containing a power switch, an on/off light to indicate suction in the pipe, and a rheostat to adjust the fan speed.

The basement slab cracks were routed and were sealed with flowable urethane. Some cracks required a small bead of Sikaflex sealant to prevent the urethane from seeping through the cracks.

With the depressurization system operating, radon levels of 0.0 pCi/L in the hallway (above the crawl space) and 0.8 pCi/L in the basement were measured with Pylons over a 2-day period in March 1988. These levels were much lower than the pre-mitigation values of 18.5 pCi/L in the hallway and 31.0 pCi/L in the basement, measured with Pylons the previous December. Pylon grab samples taken in March 1988 measured 26.4 pCi/L in the crawl-space SLD pipe, and 997 pCi/L in the basement SSD pipe, suggesting that the radon below the slab was a more significant source than was the radon under the crawl-space liner.

Pressure field extension measurements were made at seven sub-slab locations in March 1988 with the active system operating. The system was creating suctions of 0.06 to 0.56 in. WG in four test holes 1.5 to 9 ft away from the SSD pipe, directly east of the pipe toward the center of the slab. However, no suction could be detected though a test hole 30 ft away toward the slab center, or at two holes 5 to 9 ft away toward the north, near the foundation wall. These data indicated that the whole sub-slab area did not need to be under suction for the depressurization system to be effective.

The suction in the SSD pipe was 1.3 inches of water with the crawl-space SLD damper closed, but only 0.75 inches of water with the crawl-space damper open; thus, as might be expected, flows from the crawl-space SLD system (83 cfm) had a major influence on the suction in the basement SSD system. However, the SLD pipe suction was not affected by the SSD pipe damper position, due to the low flows from the SSD pipe (< 1 cfm). SLD suction was 0.80 inches of water with the SSD pipe damper closed, and remained the same with the SSD damper open.

Stage 1A

In July 1988, the in-line duct fan was removed from the basement and re-installed vertically in the exhaust pipe outdoors. This was done to prevent radon gas on the pressure side of the fan from being forced into the basement if a leak developed in the sealed joints in the exhaust piping or in the fan housing. Also, the fan speed was changed from high to medium, to determine whether this would effect the system's performance. With these modifications, the hallway radon was 0.6 pCi/L and the basement was 1.0 pCi/L. Long-term alpha-track detectors deployed from July 1988 to November 1988 measured 1.2 pCi/L in the hallway and 1.0 pCi/L in the basement. Therefore, only a slight increase in radon concentration had occurred as a result of setting the fan at a lower speed.

Stage 1B

In December 1988, the homeowner constructed a door on the crawl-space access way, to prevent cold air from passing into the basement. A hinged plywood door was installed, and openings around the door were closed using caulk on three sides, and fiberglass insulation on the fourth side. Also, the homeowner reset the fan to full speed, to provide maximum radon reductions during winter months.

Alpha-track detectors were deployed from November 1988 to February 1989. One month of the testing was with the fan speed on medium, and two months were with the fan speed on high. The hallway average radon level was 0.6 pCi/L, indicating that the radon level continued to be low.

PRE-MITIGATION DIAGNOSTIC TESTING - HOUSE 163

In October 1987, the gamma radiation level was 6 to 10 uR/hr in the basement and 12 uR/hr outside. Freon gas communication tests were performed in October 1987 by injecting freon into a sub-slab test hole located near the basement stairs. Freon gas was detected in the exhaust of a vacuum placed in a second test hole located in the northwest corner approximately 30 feet away after 6 minutes, which indicated poor sub-slab communication. Smoke tests showed there to be no air flow near the slab cracks and that air flowed from the basement through the access way to the crawl space.

REMEDIATION SYSTEM - HOUSE 163

Stage	Installation Date	System Description
1	3/88	Active sub-slab depressurization in basement, active subliner depressurization in crawl space, and sealing of slab cracks.
1A	7/88	Fan moved to exterior of house and set on medium.
1B	12/88	Crawl-space door installation, and fan set on high.

TEST DATA - HOUSE 163

PYLON MEASUREMENTS

Stage	Date	Duration (hours)	Test Condition	Location	Radon Average (pCi/L)	Radon Range (pCi/L)
--	12/87	44	Pre-mitigation	Hallway (above CS)	18.5	13-22
--	"	"	"	Basement	31.0	22-41
1	3/88	95	Fan on (high)	Hallway	0.0	--
1	"	"	"	Basement	0.8	0-3
1A	7/88	42	Fan off	Hallway	2.0	1.0-3.0
1A	"	41	Fan on (med.)	"	0.6	0.2-1.2
1A	"	42	Fan off	Basement	2.6	1.5-4.0
1A	"	43	Fan on (med.)	"	1.0	0.6-1.7

ALPHA-TRACK DETECTOR MEASUREMENTS

Stage	Date	Condition	Location	Reported Rn for each Detector (pCi/L)
1A	7/15/88-11/17/88	Fan on (medium)	Hallway (above CS)	0.7,1.6
1A	"	"	Basement	0.6, 1.4
1A/B	11/17/88-2/16/89	Fan on (medium & high)	Hallway	<0.3, 1.0
1A/B	"	"	Basement	*

* Data outside QC goals.

PYLON GRAB SAMPLES - HOUSE 163

Stage	Date	Test Condition	Location	Radon Level (pCi/L)	Progeny Level (WL)
--	6/87	Pre-mitigation	Family room	6.9	--
--	"	"	Basement	18.8	0.098
--	"	"	Crawl space	8.9	--
--	10/87	Pre-mitigation	Living room	29	0.056
--	"	"	Basement (west)	50	0.095
--	"	"	Basement (east)	31	0.073
--	"	"	Crawl space	29	0.056
1	3/88	Fan on (high)	Basement	2.4	--
1	"	"	SSD pipe	997	--
1	"	"	SLD pipe	26.4	--
1	"	"	Inside crawl space/ basement wall	1.4	--

CHARCOAL CANISTER MEASUREMENTS

Date	Test Condition	Location	Radon Level (pCi/L)	Comments
<5/86	Pre-mitigation	First floor	13.1	Owner reported
"	"	Basement	19.1	"
8/87	Pre-mitigation	Uncertain	4.3, 4.8	Owner deployed

SUCTION AND FLOW RATE MEASUREMENTS

Stage	Date	Test Condition	Location*	Suction (inches H_2O)	Flow Rate (cfm)
1	3/88	SSD open, SLD closed	SSD pipe	1.3	3
1	"	Both open	"	0.75	0.4
1	"	SSD closed, SLD open	SLD pipe	0.80	87
1	"	Both open	"	0.80	83
1	"	"	Test hole 1	0.56	--
1	"	"	Test hole 2	0.49	--
1	"	"	Test hole 3	0.14	--
1	"	"	Test hole 4	0.06	--
1	"	"	Test hole 5	0	--
1	"	"	Test hole 6	0	--
1	"	"	Test hole 7	0	--

* Numbers refer to sub-slab test hole locations (Figure 163-1).

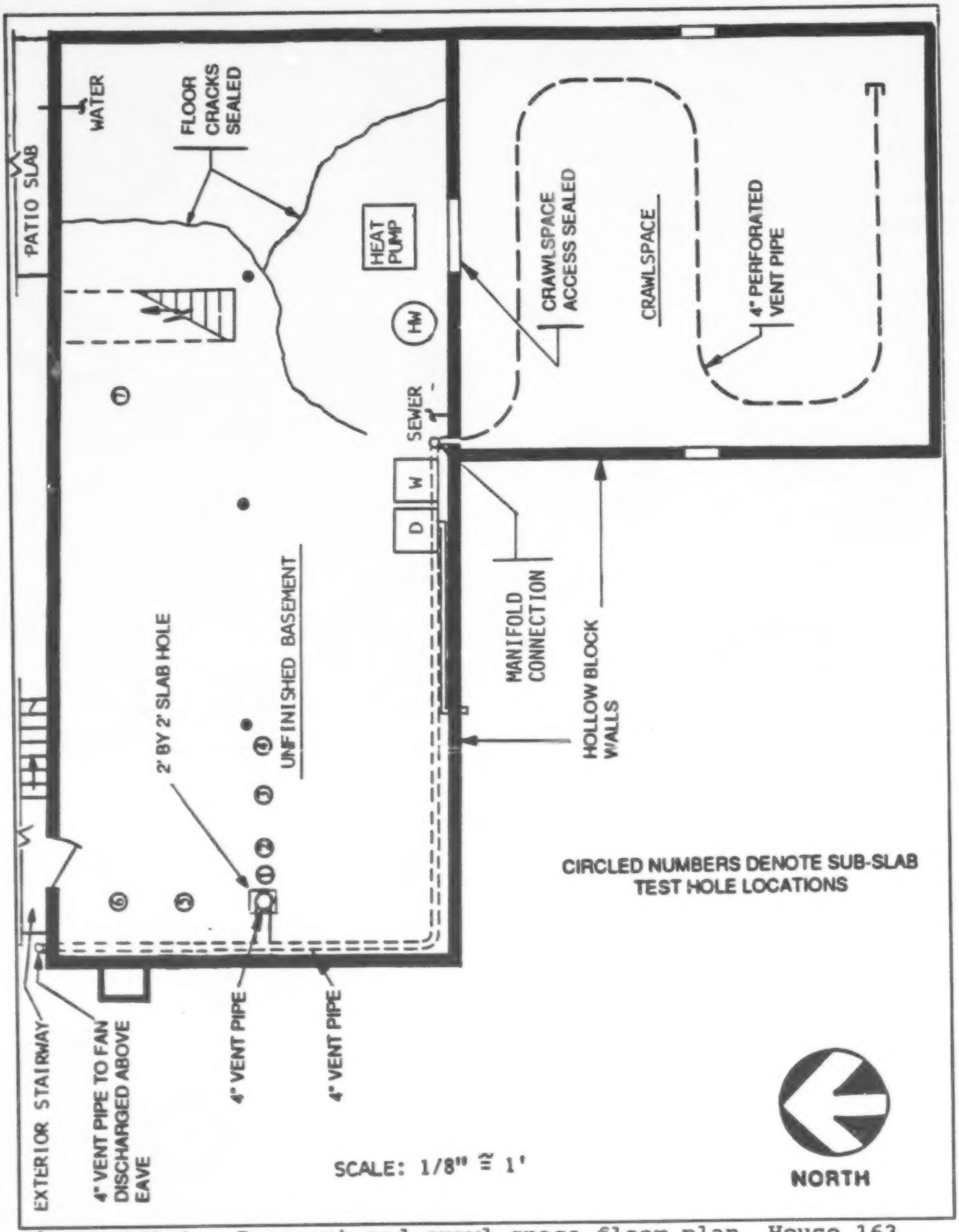

PATIO SLAB
WATER
FLOOR CRACKS SEALED
HEAT PUMP
HW
CRAWLSPACE ACCESS SEALED
CRAWLSPACE
4" PERFORATED VENT PIPE
SEWER
W
D
MANIFOLD CONNECTION
HOLLOW BLOCK WALLS
UNFINISHED BASEMENT
2' BY 2' SLAB HOLE
CIRCLED NUMBERS DENOTE SUB-SLAB TEST HOLE LOCATIONS
EXTERIOR STAIRWAY
4" VENT PIPE TO FAN DISCHARGED ABOVE EAVE
4" VENT PIPE
4" VENT PIPE
SCALE: 1/8" ≅ 1'
NORTH

Figure 163-1. Basement and crawl-space floor plan, House 163

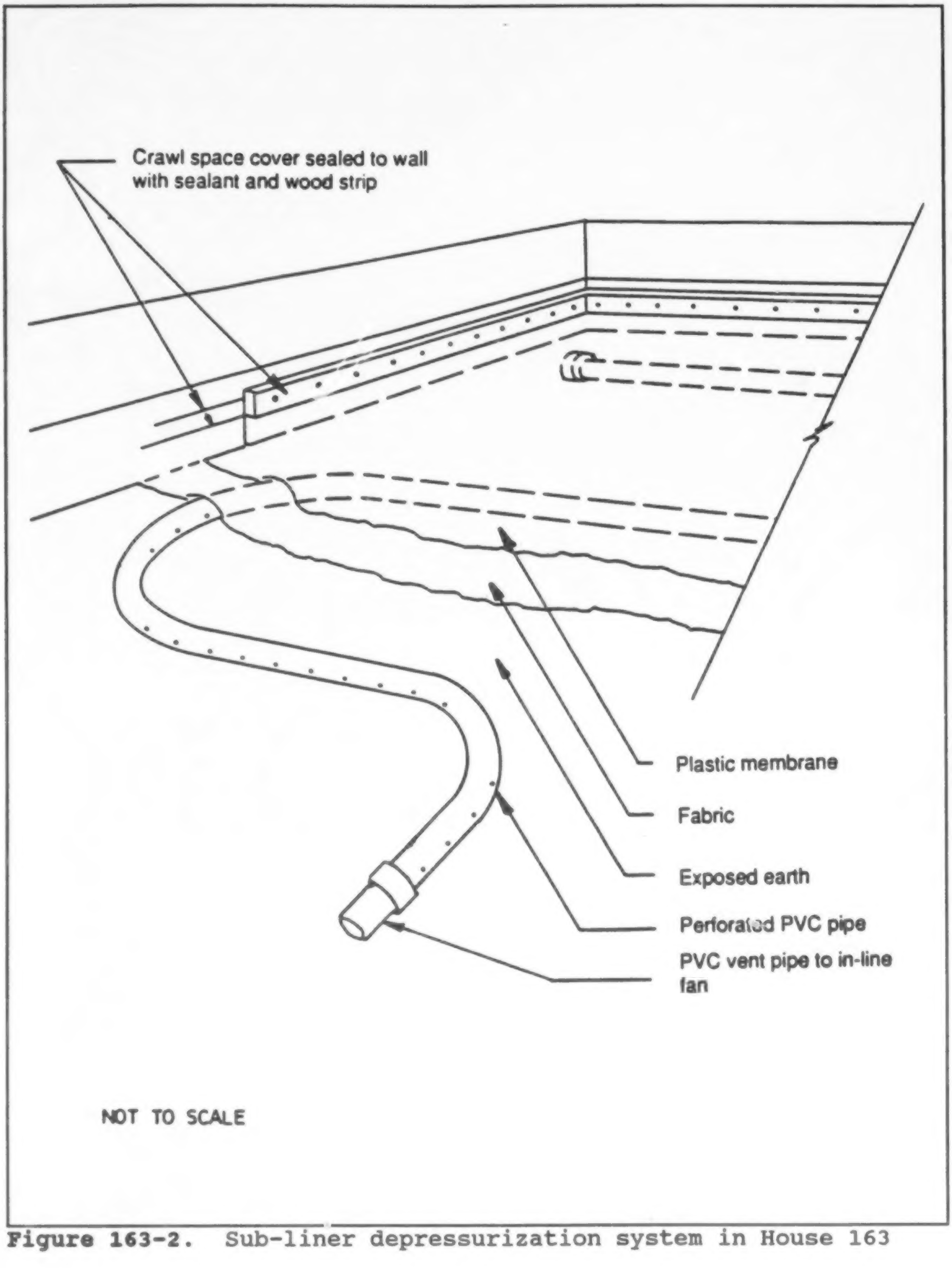

Crawl space cover sealed to wall with sealant and wood strip
Plastic membrane
Fabric
Exposed earth
Perforated PVC pipe
PVC vent pipe to in-line fan
NOT TO SCALE

Figure 163-2. Sub-liner depressurization system in House 163